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Volume XII MARCH, 1930 Number 3

THE JOURNAL OF INDUSTRIAL HYGIENE

WITH ABSTRACT OF THE LITERATURE

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The Comparative Action of 5 and 10 Per Cent. Carbon Dioxide Mixtures as Respiratory Stimulants in Carbon Monoxide Poisoning

The Quantitative Measurement of Human Efficiency under Factory Conditions

Published at Mount Royal and Guilford Aves., Baltimore, Md.
by HARVARD SCHOOL OF PUBLIC HEALTH

Entered as second-class matter, at the Post Office at Baltimore, Maryland, under Act of March 3, 1879.
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THE JOURNAL OF INDUSTRIAL HYGIENE

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CONTROL OF THE SILICOSIS HAZARD IN THE HARD ROCK INDUSTRIES. I. A LABORATORY STUDY OF THE DESIGN OF DUST CONTROL SYSTEMS FOR USE WITH PNEUMATIC GRANITE CUTTING TOOLS*

THEODORE HATCH, PHILIP DRINKER, AND SARAH P. CHOATE

From the Department of Ventilation and Illumination, Harvard School of Public Health, and the Department of Sanitary Engineering, Harvard Engineering School

INTRODUCTION

THE exposure of granite cutters to the fine dust generated in fashioning granite into building blocks or monuments has long been known to constitute a serious health hazard. The fibrotic condition of the lungs (silicosis) which results, frequently terminates in tuberculosis and accounts for the high death rates from tuberculosis of the lungs found in this industry. The hazard has been materially increased since the introduction of high speed pneumatic tools.

Although the need for dust control was therefore early appreciated, attempts to remedy the condition have been, on the whole, unsuccessful. This circumstance led us to undertake an investigation of the fundamental engineering principles involved in the design of efficient dust control systems for use with high speed pneumatic stone cutting tools. The results of the laboratory study are reported in the present paper.

*Received for publication Dec. 11, 1929.

Description of Granite Cutting Processes

In the granite cutting industry, the rough blocks from the quarry are commonly cut to dimension and their sides brought down to plane surfaces and cut with moldings, letters, or designs to meet the specifications of the work. The term "granite cutting" is applied to these particular processes.

Several types of tools, differing in operation and in the amount and kind

of dust produced, are required for the various roughing and finishing processes. The characteristics of these tools, especially as they affect the problem of dust control, will be considered separately.

TABLE 1.—HEIGHT OF BREATHING PLANE FROM STONE FOR DIFFERENT PNEUMATIC HAND TOOLS

OPERATION	HEIGHT
	in.
Four-pointing	12–15
Rough chiseling	15
Surfacing with split-chisel	12–15
Lettering	8–10
Carving	6

Hand Tools.—This group of tools includes steel chisels of various shapes. In operation they are guided by hand, and strike the stone, by the blow of a hand operated hammer, with sufficient force to shatter the minute crystals at the site of the blow. Repetition of properly applied blows results in the gradual wearing away of the stone to the desired shape. Large pieces of stone are rarely broken off during these operations, except in roughing processes when the stone is being dressed to approximate dimension. In the main, the particles are numerous and vary in size from that of a pea to microscopic dimensions, the majority falling within the latter category.

In operating these tools, the cutter works from all sides of the surface of the stone and moves the tool about as he progresses. Skill and close attention are required, particularly in cutting detail work.

Pneumatic Tools.—The pneumatic tools differ from the hand tools in that they are actuated by compressed air driven hammers, which give great force and rapidity to the blow of the tool. The increased speed of operation thus obtained is accompanied by greatly increased generation of dust and a proportionately increased health hazard.

There are two classes of pneumatic tools—the pneumatic hand tool and the surfacing machine—which differ essentially in their design and operation.

Pneumatic hand tools are used in place of the older type of hand tools for detail work—carving, lettering, and the like. The pneumatic hammer is provided in four sizes and a variety of tools are available for different types of work. The operator holds the hammer with both hands, guiding the tool over the stone with his left hand (Fig. 1). The hammer may be operated at any angle and from all sides of the stone. The rate of dust production varies with the size of the hammer, the kind of tool used, and the nature of the work. In general, the "four-point" tool, a four-pronged pick used for surfacing the stone, is the worst offender and the delicate carving chisel the least. This class of tool demands close attention to the work, as may be seen from Table 1.

The surfacing machine (Fig. 2), which is provided in two sizes, is used to bring the rough faces of the stone down to plane surfaces. By means of a graded series of tools, the machine is capable of finishing a surface to any degree of smoothness. The tools are driven by a heavy pneumatic hammer attached to a truck which runs on a horizontal arm. The arm,

in turn, swings about a vertical column and may be raised or lowered to accommodate stones of different thicknesses. The machine is sturdily constructed, to insure steadiness of operation, and the moving parts are securely supported. In operation, the hammer and tool are guided over the stone until an even surface is obtained. The tools used with the surfacer include a four-point for rough work and a bushing hammer with interchangeable sets of blades for finer finishing. The force and the frequency of the blow of the hammer—and consequently the rate of dust production—vary with the size of the machine and the type of tool used; they are greatest for the four-point and decrease for the bushing hammer with the fineness of cut.

Saw.—The saw, which may be either circular or of the reciprocating type, is used to cut rough blocks of stone into slabs of the desired size. It consists of a steel plate with a coarsely dentated edge that serves to carry steel shot against the stone, the actual cutting being done by the grinding action of the shot. In order

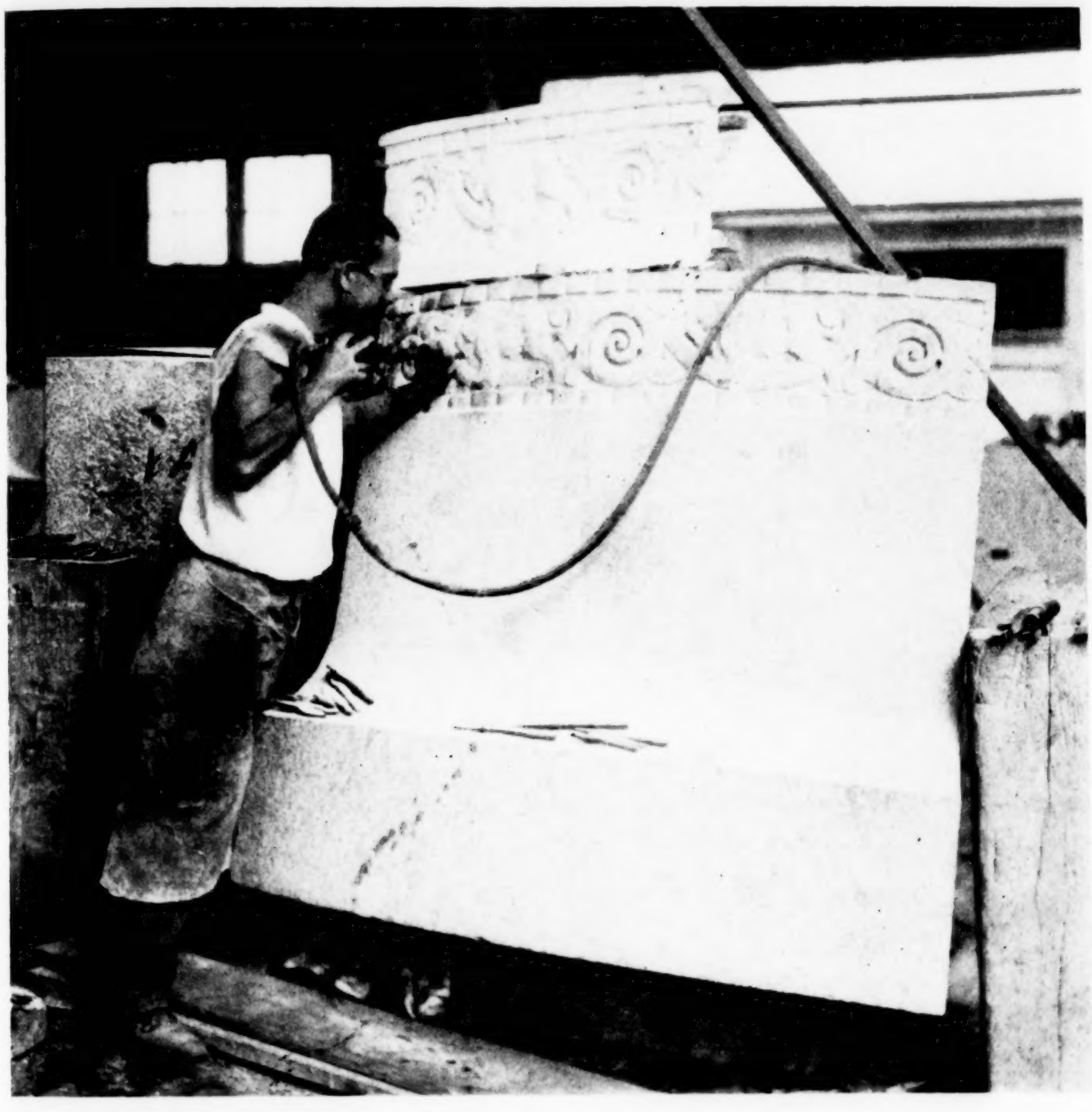

FIG. 1.—Carving with pneumatic hand tool.

that the apparatus may be kept cool and the grinding action facilitated, water is fed to the machine in a constant stream. The saw serves the same purpose as the surfacing machine

done by direct grinding action of the wheel with the aid of a stream of water. This machine displaces, in some instances, the pneumatic hand tool for this class of work.

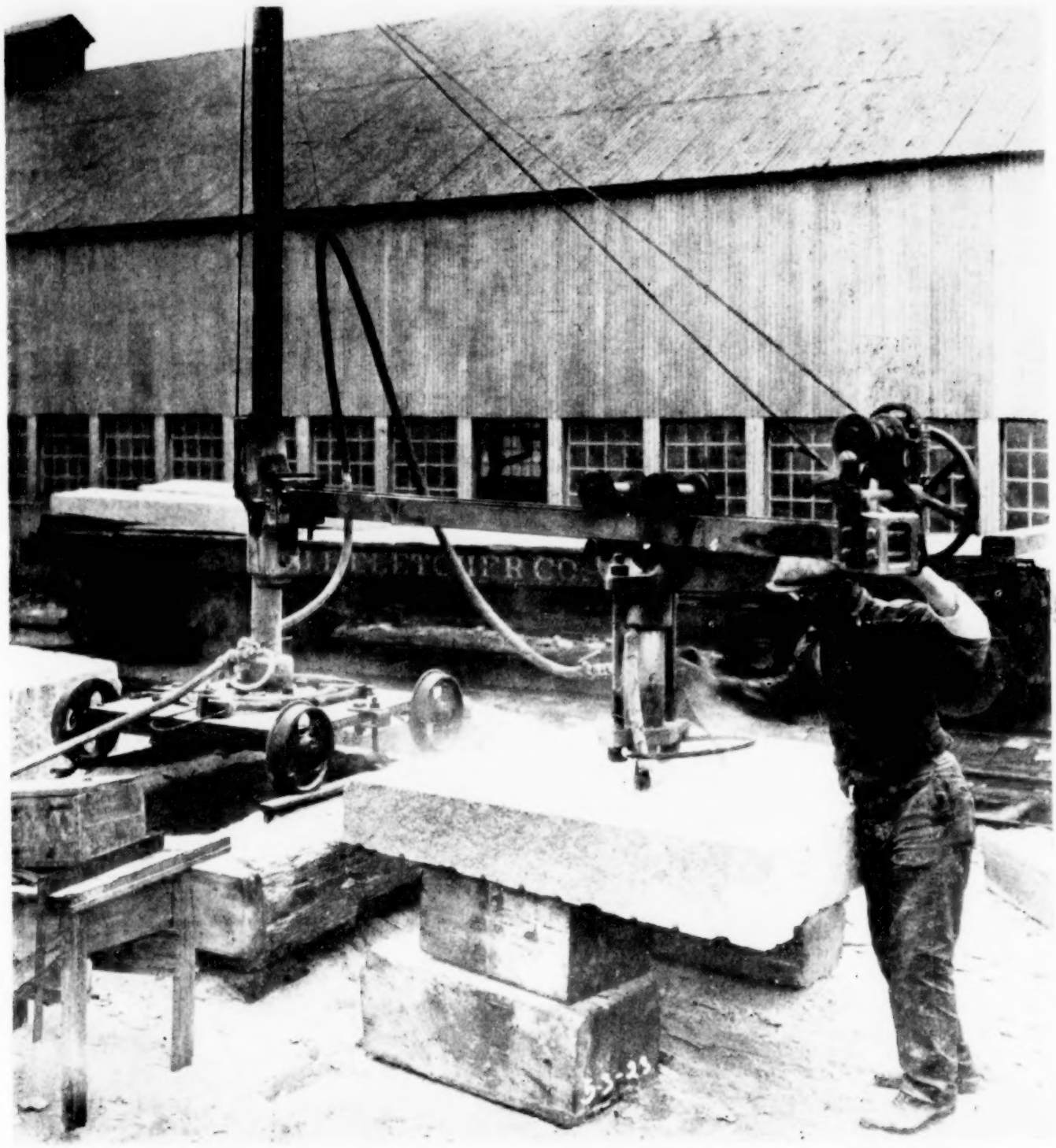

FIG. 2.—Surfacing machine.

four-point and has replaced it to a considerable extent for certain kinds of work.

Carborundum Machine.—A high speed carborundum wheel mounted on a suitable carriage is used for roughing in detail work, such as moldings and similar designs, the cutting being

Sand Blast.—Letters and simple designs may now be cut by directing a high velocity blast of sand toward the face of a stone which has previously been covered with a layer of rubber perforated by the desired design. The stone, at the exposed areas, is cut away by the impact of the sand.

This is an extremely dusty process, but its nature is such that it can be carried on within a tight cabinet by an operator who stands outside. This relatively rapid process can be used in some of the lettering and carving operations formerly carried out by means of the pneumatic hand tools.

Polishing Mill.—The polishing mill may be either hand operated or motor driven. It does its work by means of the rubbing action of a heavy steel disk which is rotated over the surface of the stone. The polishing medium consists of steel shot or carborundum grit and water.

Classification of Processes According to Dustiness

It is clear from the preceding descriptions that the various granite cutting processes differ with regard to the manner of dust production and the quantities of dust produced. In the exhaustive survey of the granite industry recently carried out by Russell and his associates (1), a complete occupational analysis was made and the cutting processes classified according to their dustiness (Table 2). The data given in this paper represent average conditions found in fourteen plants in Barre, Vt.

Standard of Permissible Dustiness

Investigations of a number of dusty trades have shown that the protective mechanism of the lungs is capable of taking care of a certain amount of inhaled dust. This limit appears to be fairly well defined and varies with the nature of the dust; it is therefore referred to as the threshold dose or standard of permissible dustiness.

Evidence of a threshold dose for the granite cutting industry was obtained in the Barre investigation. The processes were classified into four groups, according to the severity of the dust exposure, and the morbidity and mortality statistics of these groups were correlated with dust concentrations. The results indicate that no harmful effects occur when granite cutters are exposed to dust counts below a certain value. Quoting from the report (1, p. 203):

TABLE 2.—CLASSIFICATION OF GRANITE CUTTING PROCESSES BY DUSTINESS

PROCESS	AVERAGE DUST COUNT[1]
	million particles/ cu. ft.
All pneumatic hand tools	59.2
Surfacing machine, inside[2]	44.0
Surfacing machine, outside[2]	43.9
General plant atmosphere	20.2
Lathe	17.9
Polishing mill	9.0
Sandblasting	6.2
Saw	4.6
Office employees	1.9

[1] Sampled by the impinger method.

[2] Inside machines were provided with local exhaust hoods; those located outside the sheds were not equipped with dust removal devices.

> In estimating such limits consideration must be given to the record of tuberculosis and other sickness in the four dust-count groups, each having a known concentration of dust exposure. It was found that the A and B groups show unmistakable indications of the serious effect of the hazard. In those groups the average dustiness was from 40 to 60 millions of particles per cubic foot of air. Group C, which represented the occupations with a dust count equal to

that of the general plant atmosphere, showed an average of about 20 million particles. There was little indication in the study as a whole of any serious effect on the men in this group. The death certificates showed, to be sure, unusually high proportionate mortality from tuberculosis among polishers and lumpers, who fall into Group C. Confusion between occupations or change in later life from cutters to a less exacting occupation may explain part or all of the excess. But one would hesitate to be positive that no harm would come to persons working for many years under a concentration of 20 million particles. In Group D, where the average concentration was 6 million particles, there was no indication whatsoever of any unfavorable effects on health, either from the physical examinations, the sickness records, or such mortality data as were applicable to this group.

From this line of reasoning, the average dust exposure for Groups A and B must be considered as definitely harmful to the worker. There remains, then, Group C in which, with an average exposure of 20 million particles, there is some question as to the harmful effect, and Group D, with an average exposure of 6 million and a limit of 9 million, where no harmful effect is found. Thus it would appear that a safe limit lies somewhere between the amount of dustiness found in Groups C and D or between 9 and 20 million particles.

This proposed standard is of great importance in the present study for two reasons: First, it helps to differentiate the hazardous from the safe processes; and second, it will serve as a criterion of operating efficiency in the development of the dust control system.

Laboratory Studies

Scope of Investigation

Comparing the amounts of dust given off by the various cutting processes (as shown in Table 2) with the tentative standard, we find that the surfacing machine and the pneumatic hand tools produce dust concentrations considerably in excess of the safe value and that the saw, sand blast, and polishing mill, on the other hand, fall below the suggested limit. The present investigation, therefore, was directed toward the development of efficient devices for dust control in the use of pneumatic hand tools and surfacing machines. The classification given in Table 2 does not include the hand tools, which are used interchangeably with the pneumatic hand tools at the same banker. Since the hand tools throw off dust in smaller amounts, with less energy, than the pneumatic tools, however, it can be assumed that a system designed to carry off the dust generated by pneumatic tools will be more than adequate to take care of the dust produced by hand tools.

Reference has been made to the variation in dust production in the use of pneumatic tools, according to the size of hammer and the type of tool. Since the dust control system must be designed to meet the maximum requirements, the heaviest dust producer in this group—the four-point tool, whether used with the surfacing machine or used with the pneumatic hand tool—was chosen for this investigation and employed throughout. In the case of the pneumatic hand tools, the largest of the four hammers, the bull set, was used. On account of limitations of space, it was necessary to study the smaller of the surfacing machines. The results obtained with the bull set, therefore, represent the maximum for that class of tool; whereas those obtained with the surfacer would have to be increased in order to apply to the larger machine.

Method of Dust Control Chosen for Study

Of the several methods of dust control successfully employed in industry today, it is necessary to choose the one best suited to the particular conditions of the granite industry. The available methods are (*a*) general ventilation, (*b*) wetting the dust with water or other liquids, (*c*) complete enclosure of the process, and (*d*) local exhaust ventilation.

General ventilation is not likely to succeed in this instance, because dust generation in granite cutting is localized and the origin of the dust is a short distance from the breathing zone of the operator. Consequently, great volumes of air would have to be introduced in order to reduce the dust concentrations to the safe limit by this method. The wetting method is sometimes used with certain processes and serves to reduce the dust concentration. The presence of a wet mass on the stone, however, impedes the action of the pneumatic tool. The cutting operations cannot be enclosed because they demand constant hand adjustment and close attention on the part of the operator. Control of the dust at the point of generation by means of local exhaust ventilation would seem, however, to be adapted to the problem in hand, although here, also, there are practical difficulties to be overcome. Surfacing machines have been equipped with local exhaust hoods for a number of years, and in one or two instances, pneumatic hand tools have also been so equipped. Nevertheless, dust surveys have shown the existing installations to be inefficient dust collectors. In spite of this circumstance, the method was considered promising enough to warrant further study.

Fundamental Principles of Hood Design

In operation, a local exhaust hood creates an air velocity at the point of dust generation which, owing to the resisting action set up by the friction of the moving air upon the surface of the particles, counteracts the tendency of the dust to escape into the surrounding space and carries it into the collecting system. The first problem in hood design, therefore, is to determine the minimum air velocity required to produce an adequate frictional force.

This minimum air velocity depends upon the nature of the process as it affects dust production. It is determined in part, for example, by the speed with which the particles are thrown off and by their direction; for if the particles are thrown off in a definite direction, the hood can be placed directly in their path and a low air velocity will be sufficient to draw them into the collecting system. The minimum requirement in many cases can be reduced by causing the particles, as they are thrown off, to impinge against a physical barrier, thus breaking their force.

In the design of a hood to create the required air velocity, consideration must be given to a number of factors which affect the velocity at the face of the hood—the distance of the hood opening from the source of dust, the rate of air flow through the hood, and the size and shape of the hood. The laws governing these factors are not well understood, but they may be summarized briefly as follows: Air velocity decreases rapidly with

distance from the hood opening; it increases with the rate of flow through it and decreases with the size of the opening. The air velocity at a given point is affected by the shape of the hood, since shape influences the distribution of air flow in the space surrounding the hood.

Laboratory Set-Up

The stone and granite cutting tools were set up in a dust tight cabinet (2) and provided with a collecting system capable of operating over a wide range of conditions. The collecting system, shown diagrammatically in Figure 3, consisted of an attachment for hoods of various designs connected to the main system by a flexible hose, a centrifugal settling chamber in which large particles were removed, and bag filters for the removal of fine material. The system was provided with the necessary ducts, a suitable fan, and a variable speed motor. During cutting operations, the dust was removed by the exhaust system, the dusty air was passed through bag filters and, as clean air, returned to the cabinet. The filters were tested from time to time and were found to be operating at uniformly high efficiencies.

Experimental Technic

The tests, which will be described later in greater detail, consisted essentially in determining the relation between dust concentration during cutting operations at the breathing plane of the operator and the air flow through hoods of various designs. In certain cases, observations were made of air velocity distribution around hood openings.

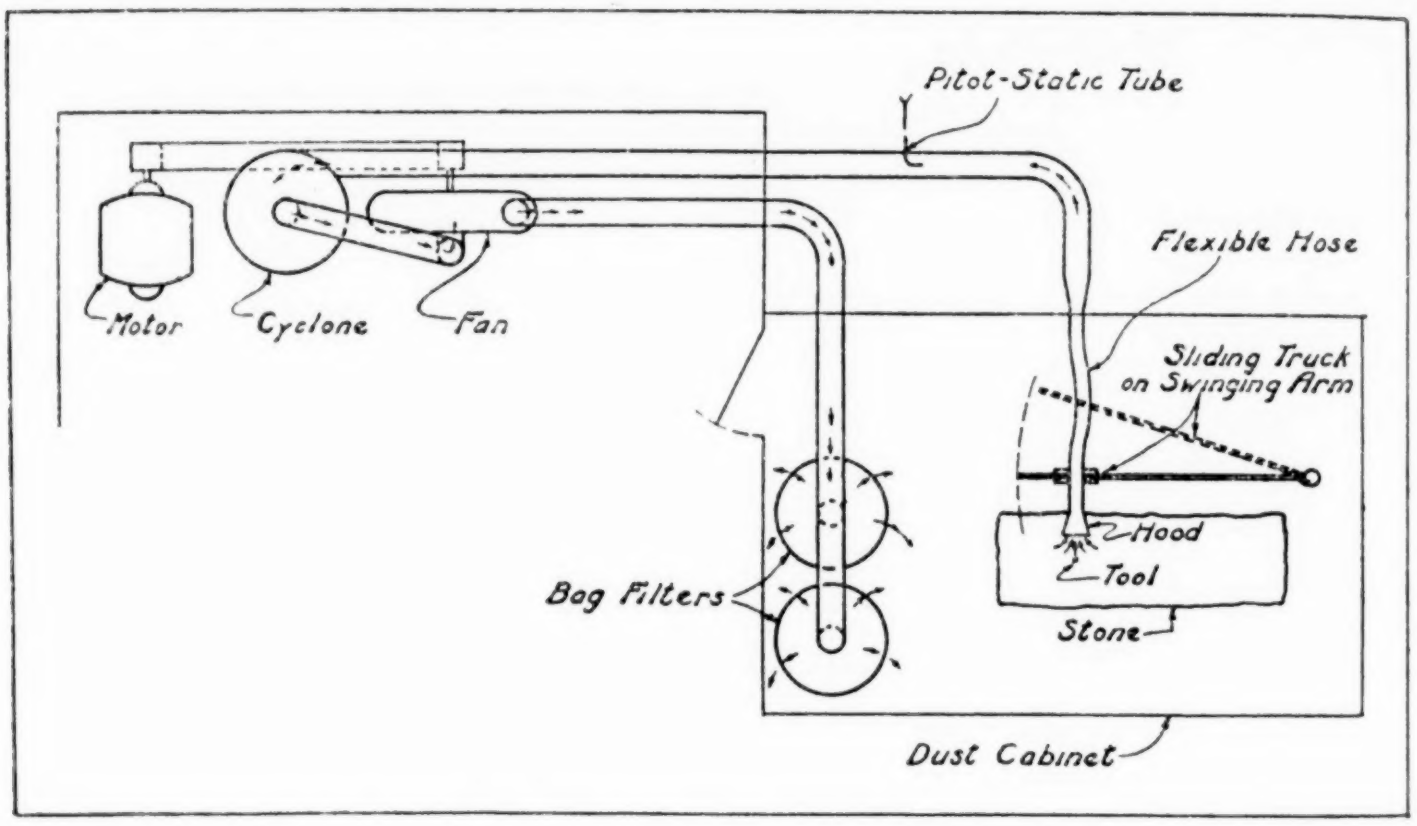

FIG. 3.—Layout of experimental dust control system for granite cutting. (Not to scale.)

Method of Cutting.—The tools were operated in the usual manner. At the beginning and during the latter

part of the study, we had the services of an expert stone cutter,[1] who taught us how to carry on the simpler operations ourselves. We believe they may be regarded, therefore, as fairly representative of field practice.

Collection of Samples.—Air samples were taken with the Greenburg-Smith impinger (3), the method used in the Barre study by the United States Public Health Service.

Sampling Point.—During the tests with the pneumatic hand tool, the impinger was kept at a constant position in relation to the tool; it was attached directly to the hood and therefore changed position with it. The sampling point was directly over the center face of the hood at a height of 8 inches above the stone. This is not the height of the breathing zone for the hand pneumatic four-point, but less variation in samples was found at this point and a comparison with the breathing zone height of 15 inches indicated similar average dust concentrations.

It was not possible to attach the impinger to the surfacing machine on account of its vibration. A stationary point was therefore chosen at the height of the breathing plane and at a radial distance from the center of the stone equal to the average distance from the tool to the face of the operator.

Method of Quantitation.—Quantitation by the standard method is time consuming, and since several samples were taken each day, it was necessary to use a quicker method. We found that, for dusts of similar size, shape, and chemical structure, the Tyndallmeter (4) gave readings proportional to the dust concentration. By calibrating the instrument against dust counts determined by the standard method (5), we were able to use it satisfactorily for quantitative measurement. The calibration curve is shown in Figure 4.

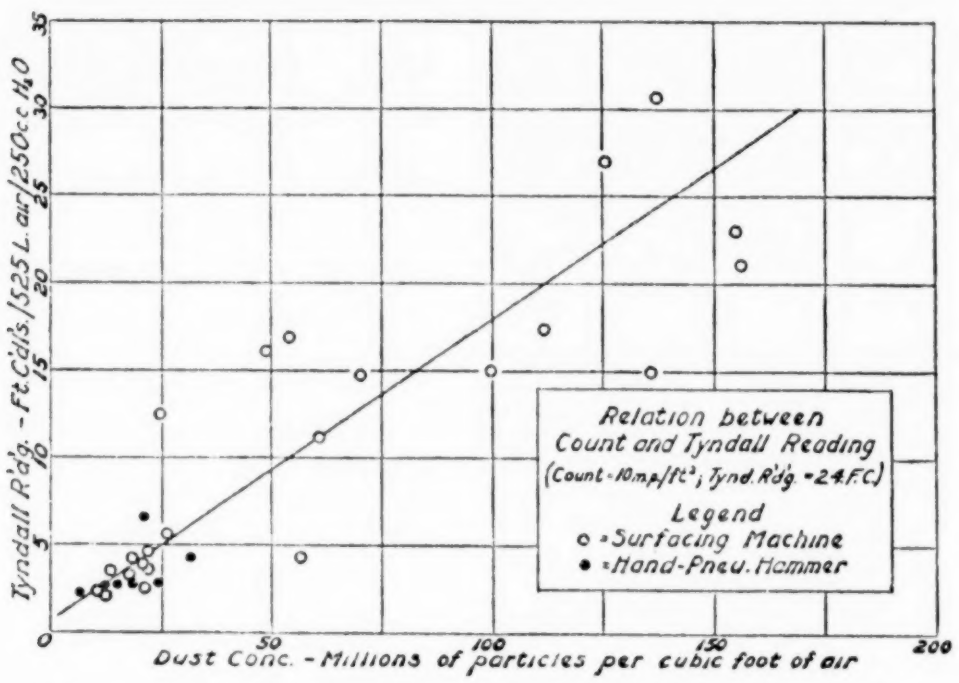

FIG. 4.—Relation between count and Tyndall reading.

Measurement of Air Flow.—For the measurement of air flow through the

[1] Mr. Michael McSheehy, whose services were provided through the courtesy of the Granite Cutters' International Association of America.

hood, a standard pitot-static tube was inserted in a main duct of the exhaust system at a point approximately ten diameters downstream from the nearest obstruction.

Measurement of Air Velocities.—A special pitot-static tube[2] designed for measuring velocity at a point in space was used for determining air velocities around the hood openings.

Control of Variation in Dust Production

In order to determine the relation between dust concentration and ventilation, it was necessary to keep the rate of dust production constant throughout the tests. It was found, during preliminary tests, that certain variable factors affected the rate—air pressure at the hammer, sharpness of the tool, condition of the surface of the stone at the beginning of the test, method of removing dust accumulated on the stone, and the interval of cutting time before sampling was started. These variables, therefore, had to be controlled or standardized, in so far as possible.

Air Pressure at Hammer.—For the pneumatic hand tool, the operating pressure was kept at 45 pounds to the square inch and was read from an ordinary pressure gauge attached to the hammer. On the surfacing machine, rapid fluctuations in pressure during operation of the hammer made it impossible to read a gauge. Care was taken, however, to see that the valve was opened to approximately the same position each time. This precaution and the general "feel" of the machine served as fairly sensitive guides.

[2] J. M. Dallavalle: Unpublished data.

Sharpness of Tool.—A freshly sharpened tool was used for each test.

Condition of Surface of Stone at Beginning of Test.—As the face of a stone approaches more nearly to a smooth surface, it becomes more "closed up" and the effective work of a given tool correspondingly decreases. As a result, the rate of dust production also decreases. For each test with the hand pneumatic four-point tool, a standard surface prepared by the surfacing machine four-point was used. In order further to control conditions, the rate of surfacing by the pneumatic hand tool was kept at 10 square inches per minute. Since the surfacing machine four-point does not close up the stone, it was not necessary to prepare a new surface for each test with this machine.

Method of Removing Dust Accumulated on Stone.—The accumulated material was removed by hand, care being taken to see that it was not thrown into the air. This was an artificial procedure, but it proved satisfactory for the purposes of these tests.

Interval of Cutting Time before Sampling.—Dust concentrations in the cabinet increased as cutting progressed, approaching a saturation or equilibrium point after, roughly, fifteen minutes for the hand pneumatic four-point and thirty minutes for the surfacing machine four-point. During the final tests, the tools were operated for these periods before sampling was started.

Data and Discussion of Results

Since the pneumatic hand tools and the surfacing machines differ greatly in their manner of operating, local

exhaust hoods for these two processes must also differ and will therefore be discussed separately.

Pneumatic Hand Tools

Characteristics Affecting Hood Design.—The design of exhaust hoods is limited, in this instance, by the following considerations: (*a*) The point of dust generation is not stationary; (*b*) the tool may be operated from all sides of the stone and at any angle; (*c*) dust is not thrown off along a definite path; and (*d*) the exhaust hood cannot be attached to the tool. The hood must thus be an entirely separate device, placed far enough away to allow the necessary movement of the tool, and operated at a rate of air flow sufficient to create the minimum air velocity requirement at the point of dust generation. It must also be capable of easy and rapid adjustment to any position demanded by the work.

Experimental Procedure.—The minimum air velocity requirement was taken to be the velocity necessary to reduce the dust exposure to ten million particles per cubic foot of air (the lower limit of the tentative standard of the Barre investigation). Four hoods of different shape were tested and curves showing the relation between dust concentration and the rate of air flow obtained for each shape. From these curves, the air flow required to keep the dust concentration down to ten million particles was determined and the air velocity at the position of the tool was measured when the hoods were operating at these required rates of flow.

The four hood shapes illustrated in Figure 5 were chosen in order to show the effect of size and shape upon the problem of design. The round, 3-inch opening (Hood No. 3) represents the conditions existing about the open end of a round hose, such as has been used in one or two plants to exhaust the dust from pneumatic hand tools. Hoods No. 1 and 2 have larger openings and were used to show any possible advantage there might be in distributing the air flow over a large area at the tool. Finally, Hood No. 1 F, a simple modification of No. 1, was chosen to show how the shape and relative position of the velocity contours could be altered by varying the design of the hood.

Results.—Curves showing the dust concentration-air flow relationship for each hood are given in Figure 5. The rate of air flow required to reduce the dust concentration to ten million particles is indicated on each curve and tabulated in Table 3. Air velocity distribution about the hood opening for three hoods operating at their minimum air flow values is shown in Figure 6. The velocity studies were limited to the distribution in a vertical plane along the center line of the hood and the data are plotted as velocity contours with the direction of flow indicated by approximate stream lines.

TABLE 3.—MINIMUM AIR FLOW REQUIREMENTS FOR PNEUMATIC HAND TOOL HOODS

HOOD NO.	AIR FLOW
	cu. ft./min.
1	307
2	321
3	258
1 F	205

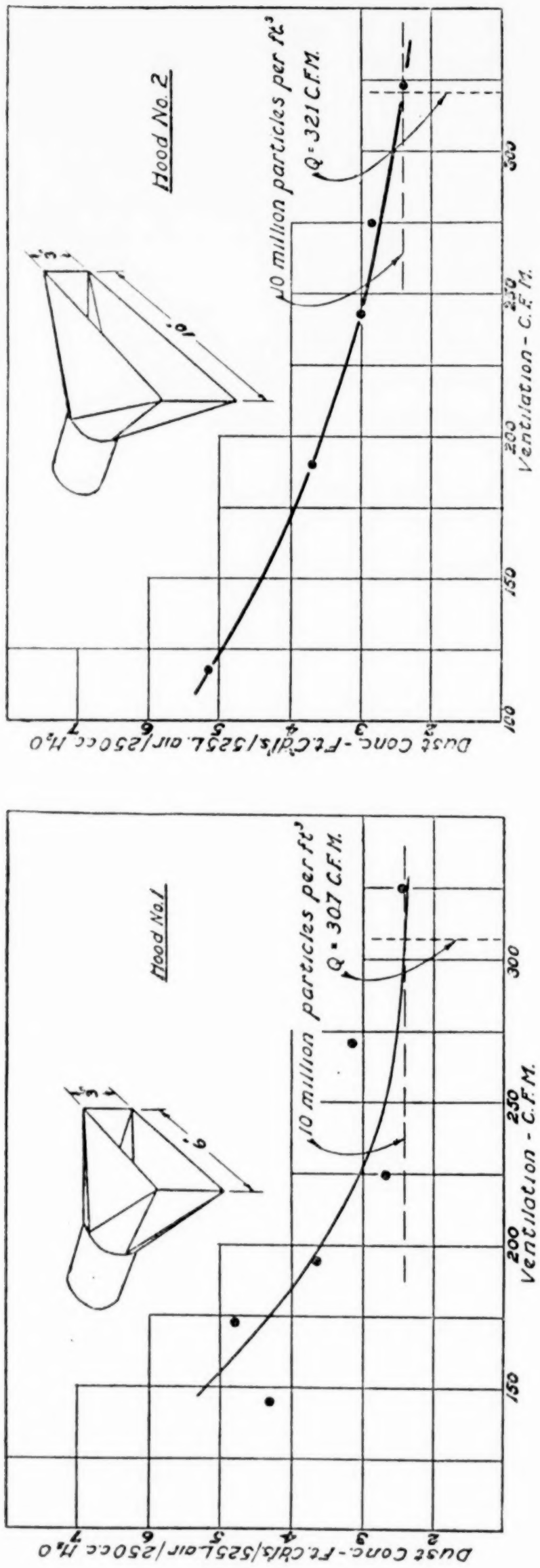
Hood No. 2
10 million particles per ft.³
Q = 321 C.F.M.
Ventilation - C.F.M.
Dust conc. - Ft. cu'ls/525 L. air/250 cc. H₂O
Hood No. 1
Q = 307 C.F.M.
Hood No. 1F
Q = 205 C.F.M.
Hood No. 3
Q = 258 C.F.M.

FIG. 5.—Relation between dust concentration and ventilation. Hoods for pneumatic hand tools.

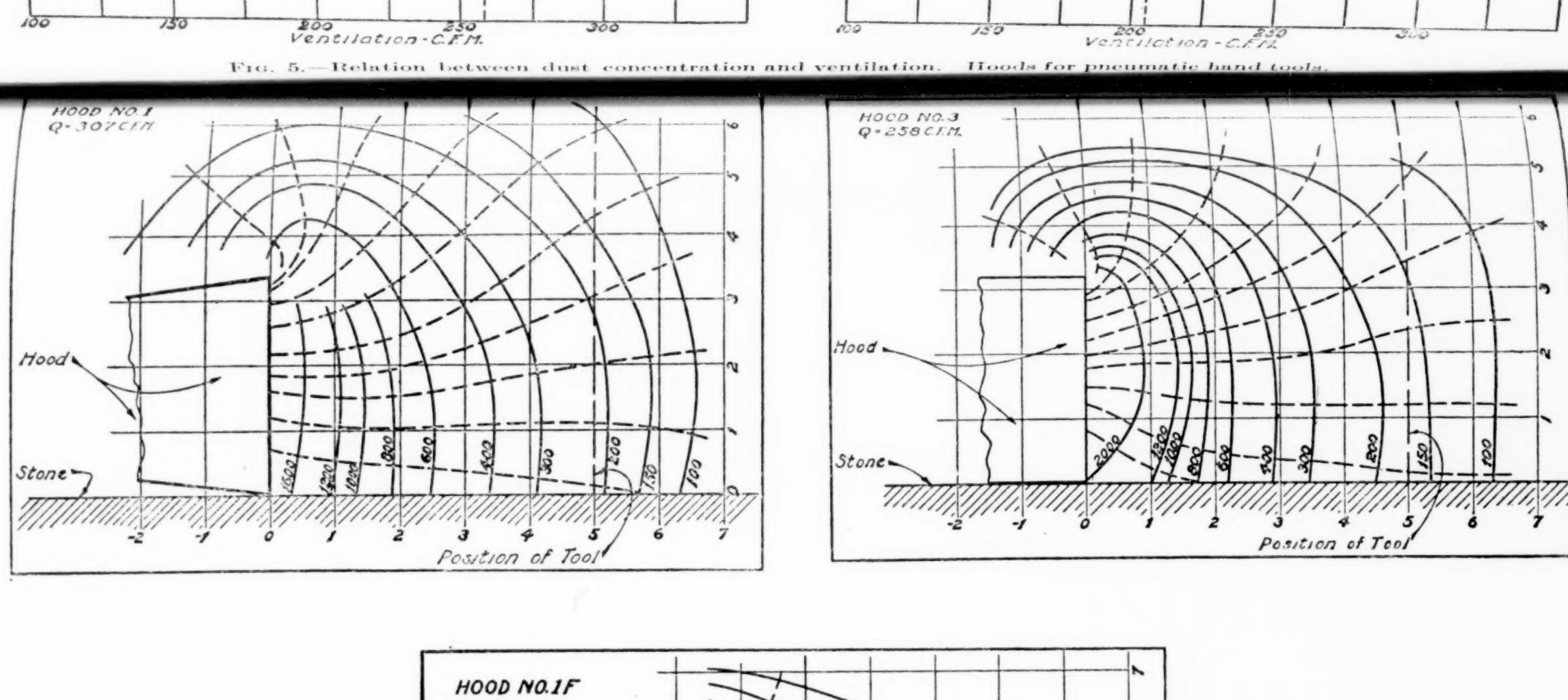

FIG. 5.—Relation between dust concentration and ventilation. Hoods for pneumatic hand tools.

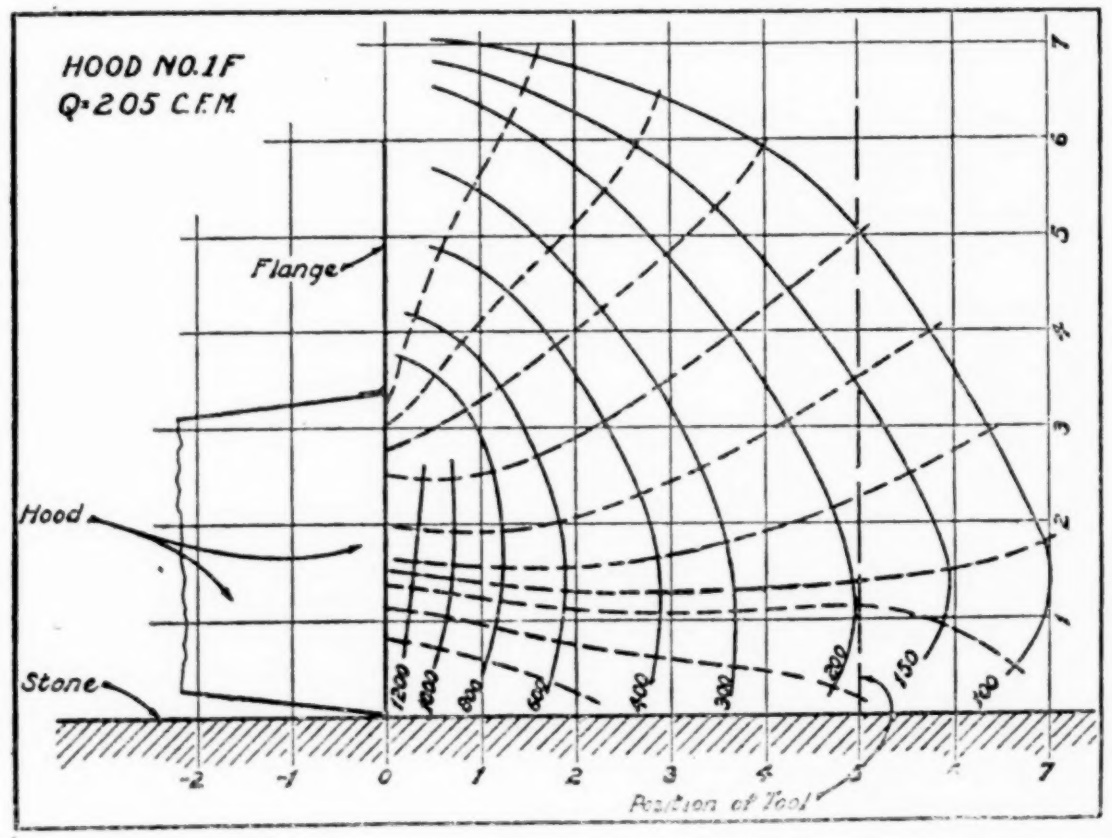

FIG. 6.—Velocity contours and stream lines in vertical plane at center line of hood.

From these curves, the required velocity at the tool was obtained.

Discussion of Results.—The most important data are those showing the air velocity requirement. From the air velocity distribution curves in Figure 6, the velocity at the position of the tool is found to be approximately 200 feet per minute for each hood. This represents (so far as the laboratory study goes) the minimum velocity requirement for the pneumatic hand tool group. It is of great importance in the design of local exhaust hoods for this process because it is entirely independent of shape, size, or position of the hood and of the air flow through it. It is a definite specification of the air velocity required at the position of the tool.

The air flow requirements for Hoods No. 1, 2, and 3 were found to increase with the area of the opening, indicating that the "effective area" about the tool is fairly small and that an increase in the area of the opening causes an increased flow from ineffective areas. From the point of view of entrance design, Hood No. 3 is unsatisfactory and a certain advantage might be gained by flaring the opening in order to reduce the pressure loss at entrance. The question of entrance design was not, however, considered in this study.

Hood No. 1F is the same as No. 1, with the exception of a flange which has been added at the face of the hood. This flange has a striking effect upon the air velocity distribution. It reduces the air flow from ineffective areas and causes a displacement of the velocity contours in an outward direction along the center line of the hood, with the result that a velocity of 200 feet per minute is created at the position of the tool by a total flow of only 205 cubic feet per minute, a reduction of 33 per cent. from the requirement of Hood No. 1.

Surfacing Machine

Characteristics Affecting Hood Design.—The design of exhaust hoods for the surfacing machine is conditioned by the following considerations: (*a*) The point of dust generation is not stationary; (*b*) the exhaust hood may nevertheless be attached directly to the pneumatic hammer; (*c*) the bushing hammer used with the surfacing machine is larger than the four-point and thus limits the closeness of fit of the hood; and (*d*) the hood may be fitted closely about the tool, every advantage being taken of physical barriers which will reduce the air velocity requirement.

Experimental Procedure.—Since the exhaust hood can be fitted closely about the tool, the minimum velocity requirement for this process depends upon hood shape and design of barriers. Our object, therefore, was to develop an opening with a low total air flow requirement, the criterion of efficiency again being reduction of dust concentrations to ten million particles per cubic foot. A number of hood shapes were investigated and several of the principles established in the preliminary studies were incorporated into the final design.

Results.—The final hood design and its dust concentration-air flow curve are shown in Figure 7. Other hoods tested during the progress of the work, and their dust concentration-air flow curves, are shown in Figure 8. The air flow requirement for each hood is tabulated in Table 4.

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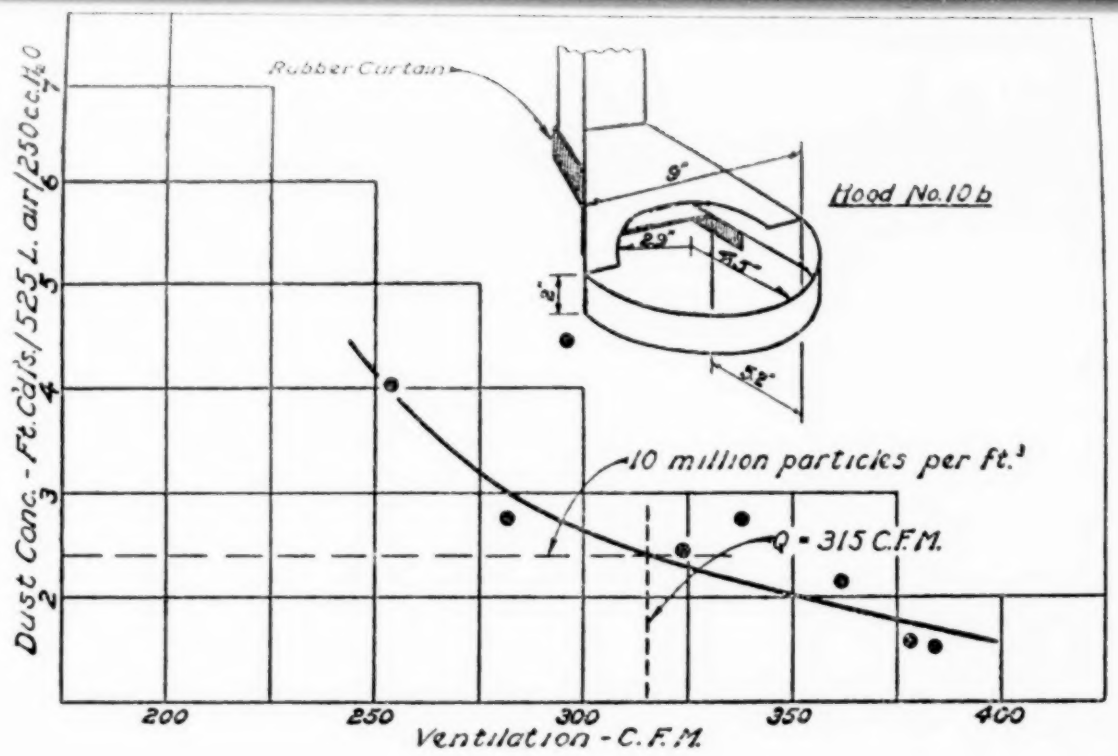
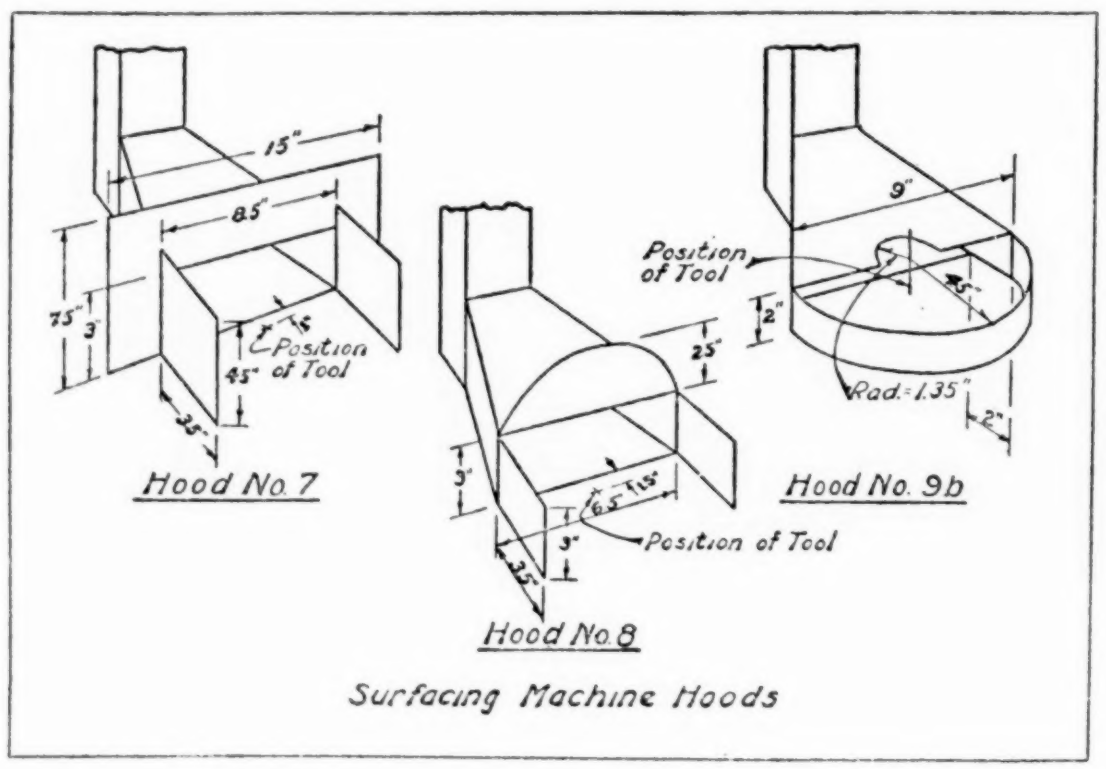


FIG. 7.—Relation between dust concentration and ventilation. Final hood design for surfacing machine.



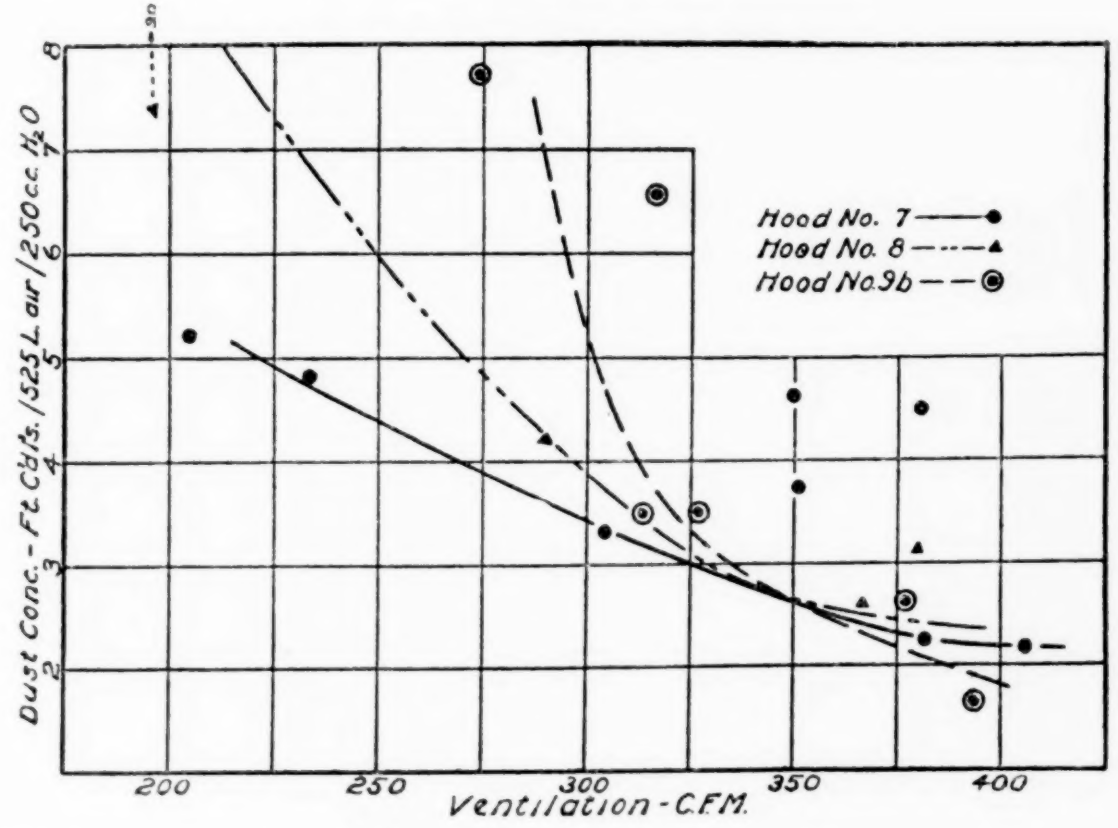


FIG. 8.—Relation between dust concentration and ventilation. Experimental hoods for surfacing machine.

TABLE 4.—MINIMUM AIR FLOW REQUIREMENTS FOR SURFACING MACHINE HOODS

HOOD NO.	AIR FLOW
	cu. ft./min.
7	370
8	394
9b	363
10b	315

Discussion of Results.—The hood finally adopted for attachment to the hammer of the surfacing machine fits closely about the bushing hammer, the largest of the tools used with this machine. The hood encloses the tool through a half circle, and a narrow band[3] completes the enclosure. This band turns aside particles thrown off at a slight angle with the stone, reducing their energy and facilitating their removal by the collecting system. The band also causes an increase in air velocity by blocking off part of the opening. The cutting back of the bottom of the hood creates a high velocity near the stone and prevents the escape of clouds of dust from the free space between the hood bottom and the surface of the stone—a region which would otherwise be an area of low air velocity. The escape of dust particles from under the hood is further hindered by a leather or rubber curtain placed around the back of the hood, which makes a contact between the hood and the stone without interfering with the movement of the tool over the stone. This curtain also increases the air flow from the direction of the tool by reducing the leakage from ineffective areas.

[3] First suggested by Mr. McSheehy.

It should be remembered that the smaller surfacing machine was used in this investigation and that the hood dimension and the minimum rate of air flow given will therefore have to be increased to meet the conditions of the larger machine.

Summary

The purpose of our study was to determine the fundamental engineering principles employed in the design of efficient dust control systems for use with high speed pneumatic stone cutting tools. Since the granite dust study at Barre, Vt., by Russell and his associates in the United States Public Health Service indicated a dust concentration of ten million particles per cubic foot of air as the highest permissible limit, we used that standard in judging the efficiency of our experimental installations.

Of the available methods of dust control, the application of local exhaust ventilation appeared to be the most promising. A study of the various granite cutting processes showed that the surfacing machine and the pneumatic hand tool alone needed investigation, since they alone produced amounts of dust in excess of the standard. The heaviest dust producing tool, the four-point, was used throughout the study.

Four different hood shapes for use with the pneumatic hand tool were tested and the minimum air velocity required at the tool to keep the dust concentration at ten million particles was determined. When the hoods were operated at the minimum rates of air flow, the velocity at the tool was found to be 200 feet per minute,

regardless of the size, shape, and position of the hood and the air flow through it. This value, therefore, may be regarded as a fundamental specification for hood design under laboratory conditions. For the field, it may have to be altered somewhat.

The hood shape finally adopted for use with the surfacing machine encloses the process as completely as possible. Physical barriers arrest the dust thrown away from the hood and high air velocities are created at strategic points without increasing the total air flow. The air flow requirement for the smaller surfacing machine was found to be 315 cubic feet per minute. A higher rate will be necessary when the larger machine is used.

We acknowledge with gratitude the advice and practical assistance received from the National Research Council; the National Building Granite Quarries Association; the Granite Cutters' International Association of America; the B. F. Sturtevant Company; the John B. Harrington Estate, Cambridge; Mr. Michael McSheehy, President of the Boston Branch of the Granite Cutters' International Association of America; and Dr. L. R. Thompson and Mr. J. J. Bloomfield of the United States Public Health Service.

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THE COMPARATIVE ACTION OF 5 AND 10 PER CENT. CARBON DIOXIDE MIXTURES AS RESPIRATORY STIMULANTS IN CARBON MONOXIDE POISONING*

DOUGLAS P. MURPHY, M.D., AND CECIL K. DRINKER, M.D.

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

THE use of carbon dioxide with oxygen in the treatment of asphyxia due to the inhalation of carbon monoxide gas is a firmly established therapeutic procedure. The mixture most commonly employed contains 5 per cent. of carbon dioxide with 95 per cent. of oxygen. Recently Drinker and Shaughnessy[1] have advocated the use of 7 per cent. of the former with 93 per cent. of the latter, especially in the first few minutes of the treatment of the more severe cases of asphyxia.

Preliminary evidence indicated that the respiratory response to carbon dioxide stimulation *decreases* as the degree of carbon monoxide asphyxia *increases*. The question consequently arises as to what is the optimum concentration of carbon dioxide for the treatment of patients suffering from the most severe grades of carbon monoxide asphyxia. It is possible that concentrations considerably higher than the customary 5 per cent. mixture may be more efficacious, or perhaps indeed be absolutely necessary, for the proper treatment of these critically asphyxiated persons.

When a patient is seriously gassed, there is urgent need for an immediate and maximum increase in the pulmonary ventilation, if his life is to be saved. It is quite possible to conceive that in certain instances the slightest delay in bringing about the maximum possible degree of ventilation may make the difference between losing a life and saving one.

The present report deals with the relative values of two carbon dioxide-oxygen mixtures as respiratory stimulants in the treatment of severe carbon monoxide poisoning. One contains 5 per cent. carbon dioxide in 95 per cent. oxygen, while the other contains 10 per cent. carbon dioxide in 90 per cent. oxygen.

It was first ascertained that when decerebrate cats which had been breathing air were shifted to the inhalation mixtures used in the carbon monoxide experiments, they responded uniformly; that is, individual cats increased their minute-volume in the same manner and to the same degree if given many three to five minute inhalations at periods not less than ten minutes apart. The fact that

* Received for publication Feb. 21, 1930.

[1] Drinker, C. K., and Shaughnessy, T. J.: The Use of 7 Per Cent. Carbon Dioxide and 93 Per Cent. Oxygen in the Treatment of Carbon Monoxide Poisoning. THIS JOUR., 1929, *11*, 301.

brief employment of the inhalation mixtures does not of itself cause a slow depreciation of response in unpoisoned animals was a necessary demonstration prior to repeated use of the mixtures during carbon monoxide poisoning.

Procedure

A group of twelve animals (adult male and female cats) formed the basis for the following observations on carbon monoxide poisoning. Of these, eight were decerebrated, while the remaining four were treated with the inhalation mixtures without the use of any anesthetic except carbon monoxide. No differences were noted between the two groups. They were prepared for the inhalation experiments as follows: (All operative procedures were carried out under ether anesthesia.) The common carotid artery was exposed so that blood samples could be secured as desired. In the case of the decerebrate animals the upper part of the trachea was opened and a cannula was inserted.

The animal was then placed in a body plethysmograph, as shown in Figure 1 *G*, with the head protruding through a close-fitting rubber collar. The respiratory passages were joined through a series of valves to an airway *A*, which was connected with three water spirometers, *B*, *C*, and *D*, containing, respectively, 0.1 per cent. carbon monoxide in air, 5 per cent.

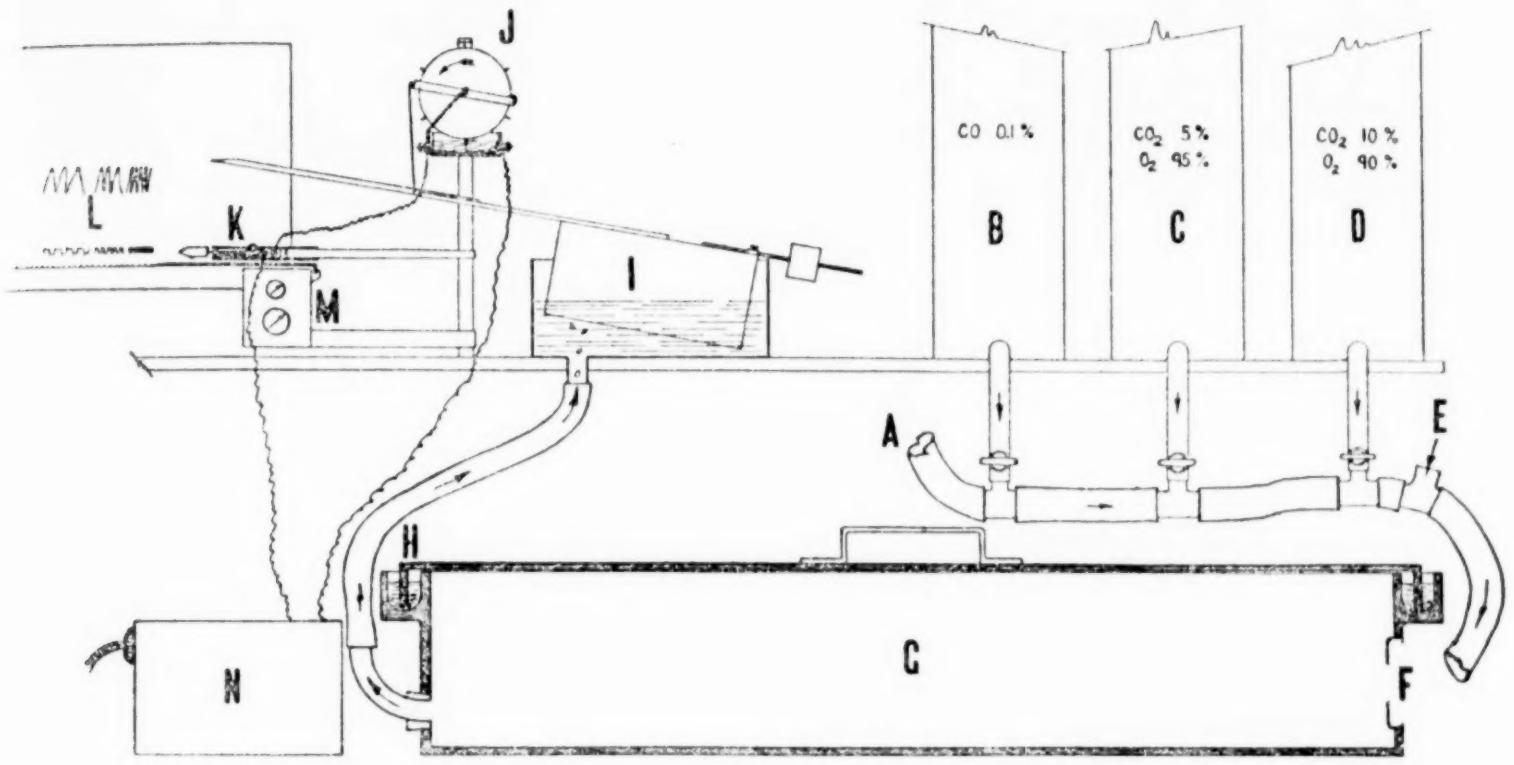

Fig. 1.—A diagrammatic drawing of the arrangement of apparatus for studying the influence of carbon dioxide and oxygen mixtures upon the breathing of animals suffering from experimentally produced carbon monoxide poisoning.

A. Airway connecting with spirometers B, C, and D, and with inlet for air breathing E.

F. Opening in end of body plethysmograph G fitted with rubber collar through which animal's head extends.

H. Mercury seal of plethysmograph.

I. Krogh spirometer.

J. Work adder with mercury contact connected with lever of Krogh spirometer and with writing point of electromagnet K.

L. Smoked paper on kymograph exhibiting samples of tracings produced by writing point of work adder electromagnet at various respiratory rates.

M. Time marker.

N. Resistance box.

carbon dioxide gas in 95 per cent. oxygen, and 10 per cent. carbon dioxide gas in 90 per cent. oxygen, and with an inlet for air breathing *E*. The gas and air mixtures were led to the lungs of the decerebrate animals through a two-way Krogh valve into a tracheal cannula. The intact animals breathed through a glass hood covering the head. The plethysmograph was connected with a previously calibrated Krogh spirometer *I*, which in turn was connected with a work adder *J*.

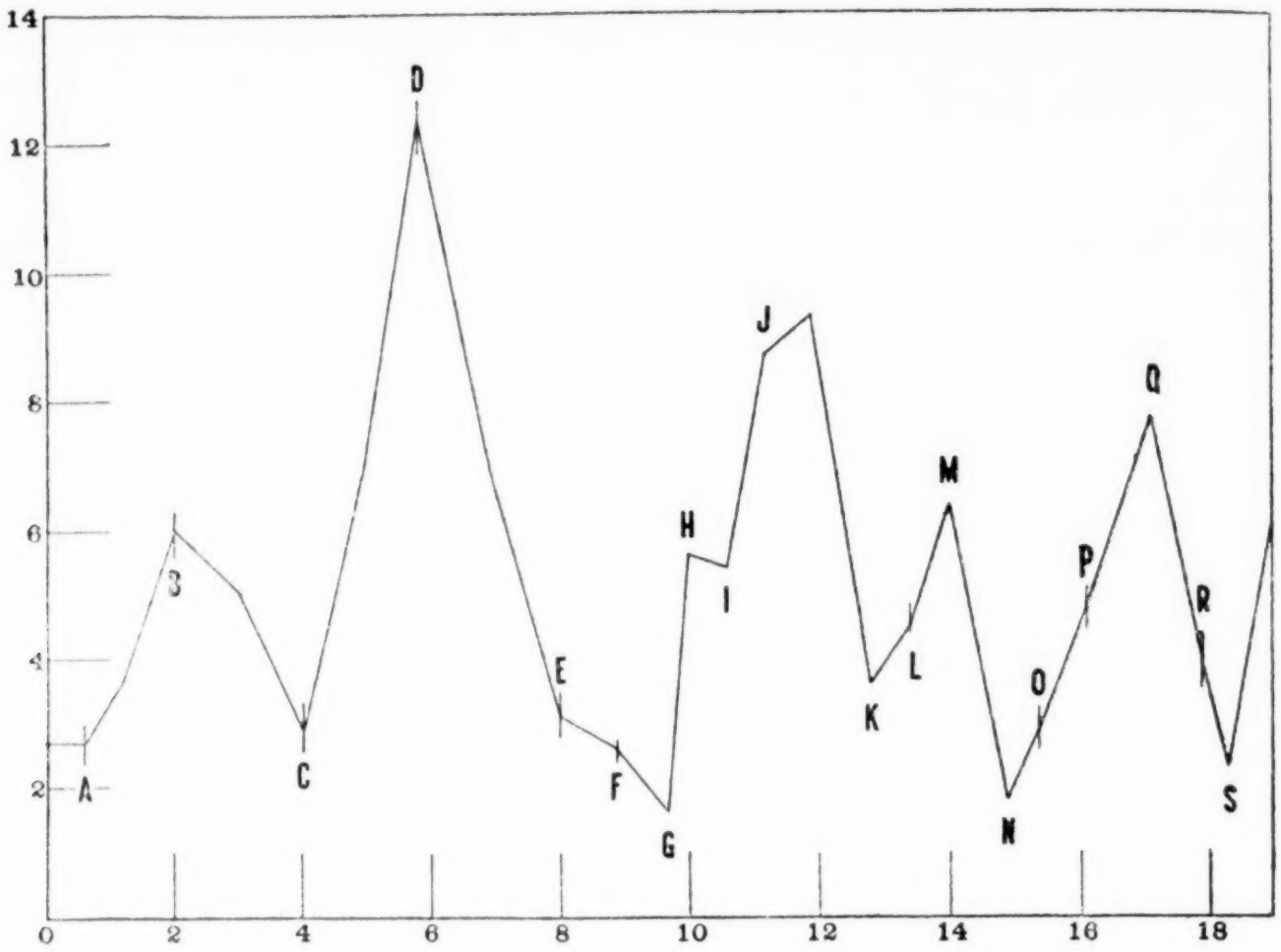

FIG. 2.—Showing influence of 5 per cent. carbon dioxide in oxygen and of 10 per cent. carbon dioxide in oxygen upon ventilation rate of decerebrate cat, before and after onset of carbon monoxide poisoning. Before onset of carbon monoxide poisoning the mixtures were administered for three minutes, after onset of poisoning they were administered for one minute.

Ordinates indicate ventilation rate in cubic centimeters of air moved, expressed in units of 500. Abscissas record the time, expressed in units of 100 seconds.

A. 5 per cent. carbon dioxide.
B. Air.
C. 10 per cent. carbon dioxide.
D. Air.
E. Blood sample taken and inhalation of 0.1 per cent. carbon monoxide begun.
F. Interval of 21 minutes of carbon monoxide inhalation not included in curve.
G. Blood sample taken, 43.9 per cent. carbon monoxide saturation.
H. 5 per cent. carbon dioxide.
I. 10 per cent. carbon dioxide.
J. Carbon monoxide.
K. Blood sample taken, 42.3 per cent. carbon monoxide saturation; 5 per cent. carbon dioxide.
L. 10 per cent. carbon dioxide.
M. Carbon monoxide.
N. Blood sample taken, 66.3 per cent. carbon monoxide saturation; 5 per cent. carbon dioxide.
O. 10 per cent. carbon dioxide.
P. Carbon monoxide.
Q. 5-minute interval not otherwise recorded.
R. 5 per cent. carbon dioxide.
S. 10 per cent. carbon dioxide.

Note that at H and at R the 5 per cent. mixture was ineffectual while the subsequent inhalation of the 10 per cent. mixture increased the ventilation rate.

With this arrangement completed, the procedure for carrying out the inhalation tests was as follows: The character and volume of normal

breathing were first noted. Records were then made of breathing: (1) during inhalation of the 5 per cent. carbon dioxide mixture for a period of three minutes; (2) during air breathing which continued until the respiration had returned to normal; and (3) during inhalation of the 10 per cent. carbon dioxide mixture for a three-minute period. (Fig. 2, *A* to *D*.)

With the foregoing records as controls, the animal was subjected to a period of carbon monoxide inhalation, for which a concentration of 0.1 per cent. of pure carbon monoxide in air was used. At the first evidence of definite respiratory difficulty, a blood sample was taken from the exposed carotid artery and the breathing was changed from the carbon monoxide mixture to the 5 per cent. carbon dioxide mixture. This was allowed to continue for sixty seconds. If, at the end of this period, there was a noticeable increase in the ventilation as indicated by the electromagnet attached to the work adder, Figure 1 *K*, carbon monoxide inhalations were resumed until there was a more decided alteration in the respiratory response. At this point a second test was undertaken, and the same procedure repeated until a point was reached at which no response followed the sixty-second inhalation of the 5 per cent. mixture. Then at once the 10 per cent. mixture was thrown into the system for a sixty-second interval, following which the carbon monoxide mixture was reintroduced. At irregular intervals for the remainder of the animal's life, the test was repeated until a point was reached at which even the 10 per cent. mixture was incapable of producing any increase in ventilation.

Effect of the Mixtures

Before Pure Carbon Monoxide Inhalation

It was always observed that both the 5 per cent. and the 10 per cent. carbon dioxide mixtures brought about a marked increase in respiratory activity. The 5 per cent. mixture gave an increase in respiratory response which varied from 57 to 339 per cent., with an average increase of 148.5 per cent. for the twelve animals investigated. The 10 per cent. mixture induced an increase in response which varied from 104 to 760 per cent., with an average of 280.1 per cent. This represented approximately twice the response elicited by the 5 per cent. mixture. In other words, there was a direct proportion existing between the concentration of the carbon dioxide mixture used and the degree of increased pulmonary ventilation elicited by it. In each case the inhalation was limited to a three-minute period.

The variations in degree of response to the same concentration of carbon dioxide exhibited by different animals are shown also in human beings.[2] In the fact that a number of normal persons respond with only a moderate increase on breathing 5 per cent. carbon dioxide, we have one reason for recommending 7 per cent. carbon dioxide for inhalation mixtures in treating carbon monoxide poisoning.

[2] Heller, E., Killiches, W., and Drinker, C. K.: The Evaluation of 5 and 7 Per Cent. Carbon Dioxide Mixtures as Respiratory Stimulants. This Jour., 1929, *11*, 293.

After Pure Carbon Monoxide Inhalation

Except as they were influenced by the degree of carbon monoxide poisoning existing at the moment that the various tests were instituted, all the animals responded quite uniformly to the stimulating influence of the two carbon dioxide mixtures. When the asphyxia was relatively mild, both mixtures tended to increase the volume of ventilation. When it was extremely severe, neither of them seemed to have the slightest effect. In the intervening degrees of asphyxia, the 5 per cent. mixture caused no increase in the respiration. There was, however, an increase when the 10 per cent. mixture was employed.

In all, thirty-three tests were made, in which the 10 per cent. mixture was inhaled after inhalation of the 5 per cent. mixture. The results were as follows: In nine tests (mild poisoning) responses followed the inhalation of both mixtures; in three tests (severest type of poisoning) no response was observed following the use of either mixture; and in twenty-one instances (moderate poisoning) the 5 per cent. mixture produced no stimulating effect, while the 10 per cent. mixture increased the pulmonary ventilation.

Our interest naturally centers upon the tests in which 5 per cent. carbon dioxide was not effective while 10 per cent. was, and upon those in which neither concentration of carbon dioxide caused stimulation. A typical experiment is shown in Figure 2. Before inhaling carbon monoxide this animal gave the responses shown by peaks *B* (5 per cent. carbon dioxide) and *D* (10 per cent. carbon dioxide). At *E*, inhalation of 0.1 per cent. carbon monoxide began. This continued to *H*, a total period of twenty-four minutes and twenty seconds, when 5 per cent. carbon dioxide was administered and no effect obtained. The animal at this time was 43.9 per cent. saturated with carbon monoxide, and when carbon dioxide was given, was breathing vigorously owing to the recent manipulation of the carotid artery incident to taking the blood sample. At *I*, 10 per cent. carbon dioxide gave a strong increase in breathing. Later in the experiment at *K* and at *N*, 5 per cent. carbon dioxide caused an increase in breathing. At *R*, when the animal was still breathing well but was obviously beginning to fail rapidly, 5 per cent. carbon dioxide was ineffectual in arresting the decline of respiration, whereas 10 per cent. carbon dioxide at *S* checked it at once.

The same failure to arrest a decline in breathing late in carbon monoxide poisoning is seen at *I*, Figure 3. Here 5 per cent. carbon dioxide had no effect whatsoever, but 10 per cent. carbon dioxide at *J* gave excellent stimulation. In animals breathing slightly and showing no increase upon inhalation of either gas mixture, it has been possible to obtain an excellent degree of stimulation from 10 per cent. carbon dioxide by applying artificial respiration in conjunction with it for a short period. This experience is in accord with the clinical experience of one of us (C. K. D.). Directions for resuscitation not infrequently advise that if the patient is breathing at all, artificial respiration should not be employed. Such practice is not in accord with our experience. If a patient suffering from carbon monoxide

poisoning does not at once increase his breathing when given the inhalation treatment, artificial respiration by the prone pressure method should be started and the inhalation continued. In a short time, five to ten minutes, the patient will usually begin to breathe vigorously, and it will be possible to cease artificial respiration. There seems to be a period in advanced carbon monoxide poisoning when the threshold for stimulation of the respiratory center is high, probably owing to lack of oxygen. In order to have stimulation by carbon dioxide effective, one must first get oxygen into the blood in as large an amount as can be carried. This oxygen causes a reduction in threshold for stimulation of the cells of the respiratory center and thus enables the carbon dioxide in the inhalation mixture to increase breathing.

There is no justification for withholding artificial respiration in carbon monoxide poisoning if the observer believes that his efforts will increase the ventilation over that existing at the moment. If inhalation mixtures are available, it is especially necessary to give artificial respiration in order to bring the treatment to maximum efficiency with as little delay as possible.

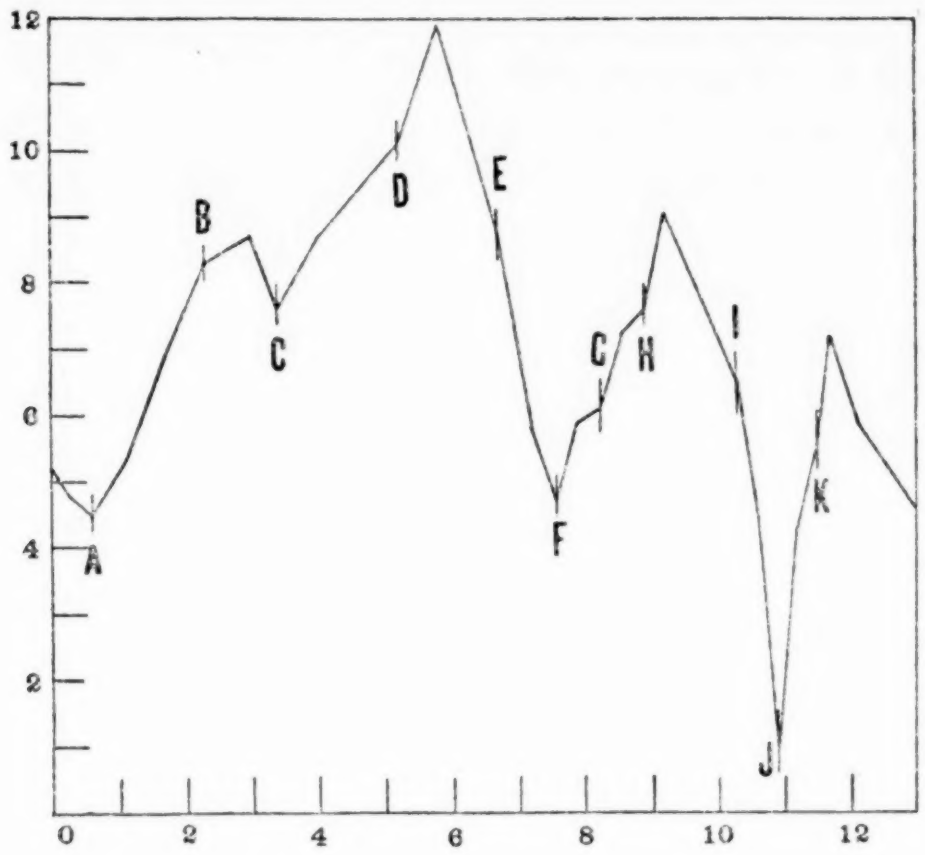

FIG. 3.—Showing influence of 5 per cent. carbon dioxide in oxygen and of 10 per cent. carbon dioxide in oxygen upon ventilation rate of an adult cat before and after onset of carbon monoxide poisoning. Periods of administration were the same as in Figure 2.

Ordinates indicate ventilation rate in cubic centimeters of air moved, expressed in units of 400. Abscissas record the time, expressed in units of 100 seconds.

A. 5 per cent. carbon dioxide.
B. Air.
C. 10 per cent. carbon dioxide.
D. Air.
E. Inhalation of 0.1 per cent. carbon monoxide for the period recorded and for an additional 56 minutes not forming part of the curve.
F. 5 per cent. carbon dioxide.
G. 10 per cent. carbon dioxide.
H. Carbon monoxide.
I. Blood sample taken, 49.9 per cent. carbon monoxide saturation; 5 per cent. carbon dioxide.
J. 10 per cent. carbon dioxide.
K. Air.

Note that at I the 5 per cent. mixture was ineffectual while the subsequent inhalation of the 10 per cent. mixture increased the ventilation rate.

Discussion

That carbon dioxide is the respiratory stimulant par excellence cannot be doubted. The experiments reported by us in no sense negative this fact and make no brief for discarding or limiting the inhalation treatment of carbon monoxide poisoning. It is common knowledge in connection with all stimulating substances that the effectiveness of a stimulant may be altered by the condition of the recipient. One can poison cats with carbon monoxide and reach a point where the animal is still breathing, though slightly, and obtain a situation in which oxygen alone and 5 per cent. carbon dioxide plus 95 per cent. oxygen are breathed for some minutes with equally inconspicuous results. If, however, one gives artificial respiration for a short time, so that the maximum possible oxygenation is secured, the carbon dioxide mixture will show superiority. The practical aspect of such observations is, of course, that it is not sufficient to place patients with carbon monoxide poisoning simply upon inhalation treatment. In order to be certain that the best is being done for them, this treatment should be coupled with such handling as will insure optimum results.

The fact that 10 per cent. carbon dioxide was used in the experiments reported in this paper should not be taken as a recommendation for the use of this mixture in human work. Cats are more resistant to carbon dioxide than are men, but their response does not differ in kind. These experiments do, however, place further emphasis upon the use of the 7 per cent. mixture, which was suggested by Drinker and Shaughnessy for the initial period of treatment of carbon monoxide poisoning and which was chosen by them because it apparently could cause no untoward effects. If higher concentrations are used, this should be done under conditions permitting a careful record of their action.

Summary and Conclusions

1. A series of twelve adult cats were subjected to progressive carbon monoxide poisoning until death resulted.

2. Inhalation of 5 and 10 per cent. mixtures of carbon dioxide and oxygen were permitted at various stages during the progress of the poisoning in order to determine their relative powers as respiratory stimulants.

3. Early in the asphyxia, stimulation followed the inhalation of both mixtures. Later, the 5 per cent. mixture gave no stimulation, while the 10 per cent. mixture still elicited some response. At the end of the experiment, or near the death of the animal, neither of the mixtures was in any way effectual in increasing the ventilation rate.

4. From these observations two conclusions are reached: First, that 10 per cent. carbon dioxide is more effectual in the treatment of certain degrees of carbon monoxide asphyxia than is the 5 per cent. mixture; and second, that artificial respiration should be administered to patients who are breathing but who are suffering from severe grades of asphyxia. In these persons a brief period of artificial respiration will induce conditions favorable to the stimulation of breathing by the carbon dioxide in the inhalation mixtures.

THE QUANTITATIVE MEASUREMENT OF HUMAN EFFICIENCY UNDER FACTORY CONDITIONS*

OSGOOD S. LOVEKIN

Department of Industrial Research, Harvard Graduate School of Business Administration, Boston, Mass.

INTRODUCTION

DEFINITION OF EFFICIENCY

THE physicist defines efficiency as the simplification of the fraction $\frac{\text{output}}{\text{input}}$, and gets his result as a percentage. When one observes human activity the problem is essentially the same, and one might define efficiency as output per unit of energy expended in attaining this production. It is possible in the laboratory, where complete facilities for measurement exist, to compute the efficiency of the human machine in the strict sense, and to get a percentage figure, where both terms of the fraction are expressed in the same units. But in most kinds of human effort it is impossible to go this far in measurement. One is confronted with a chaos of different units which defy any effort to reduce them to a common basis. Efficiency becomes a vague term which emphasizes the actual amount of production. The typical factory foreman, if asked to point out the most efficient worker in a department, will usually choose the one who produces the most. In the long run he is probably justified, for those who can maintain a high output month after month are sure to be using effectively the energy they put into their work. But there is often need for more accurate measurement of efficiency of individuals and of groups, and the investigation which examines output alone is incomplete. One should simultaneously get production records and observations on organic and psychologic behavior—the so-called nonperformance tests of the British investigators (1). These latter observations should, if one wishes to talk about efficiency, be translatable in terms of energy expenditure. In other words, we should be examining the effect of various levels and durations of activity on output, a more fruitful approach to the problem of fatigue, as Muscio (1) has pointed out, than a search for some sort of measurable entity that could be given that name.

SCOPE OF STUDY

For use in the factory, determinations of energy expenditure must be made quickly and must involve simple apparatus so as to upset the normal working environment as little as pos-

* Received for publication Dec. 12, 1929.

sible. This paper deals with work done on blood pressures and pulse rates in a number of different laboratory and factory situations. Blood pressure readings can be quickly made and the apparatus is simple. The chief defect lies in the need for uniform skill in making the readings. These determinations, except in certain indicated exceptions, have all been made by one observer, Miss Emily Osborne, who from long practice has acquired a high degree of skill in making quick and accurate readings. The laboratory experiments were designed to establish standards and give correlations that could be applied under actual factory conditions; consequently these experiments, and the conclusions to be drawn from them, will be discussed first.

Laboratory Experiments

Blood Pressure and Pulse Rate Readings as Measures of Energy Expenditure in Muscular Work

One of the best measures of the energy expenditure in muscular work is the consumption of oxygen. Oxygen cannot be stored in the body; hence the consumption of oxygen per minute varies almost directly with the work done in the same time. "The relationship is so close that the oxygen-consumption of the body during exercise is now usually taken as a measure of its intensity" (2, p. 24).

Another good measure of energy expenditure is blood flow. Taking the oxygen consumption of the body as a measure of its metabolic activity, certain experimenters "find that the output of the heart per minute runs practically parallel with the consumption of oxygen; . . . . . In some of Lindhard's and of Means' and Newburgh's experiments . . . . . an almost linear relationship was observed between the [external] work performed and the output of the heart" (2, p. 49). This relationship was confirmed in work by Bock, Dill, and others (3, p. 144).

A number of investigators have studied the relation of heart output to blood pressure and pulse rate. Addis (4) made observations on normal people before and after progressively increasing amounts of muscular work. He found in general that immediately after work the systolic pressure was higher, the diastolic was lower, and the pulse pressure[1] and pulse rate were higher. The pulse product[2] alone, however, showed a proportionate increase with increased work. Skelton (5), testing the proposition with a perfused heart, found no proportionate relations, and therefore denies that the pulse product is of any value in showing heart output; but Wiggers (6) points out that Skelton's own tables show that although there is not always a proportionate increase, there is without fail a change in the same direction as the change in the minute discharge. Erlanger and Hooker (7) concluded that volume discharge and pulse pressure varied directly.

The writer did not find in the literature any direct comparisons between

[1] Difference between systolic and diastolic pressures.

[2] Product of pulse pressure multiplied by pulse rate.

pulse product or pulse pressure and oxygen consumption.

Bicycle Experiments (Sprints)

The oxygen consumption, carbon dioxide output, blood flow, lactic acid, blood pressure, and pulse rate were observed simultaneously in three subjects at different levels of exertion in the following experiments. The work was done on a bicycle ergometer, to which an adjustable brake band was attached. The subjects pedaled at the same speed in all the experiments, and were made to work at different levels of exertion by changes in the tension on the brake. The period of work was, with three exceptions, twenty minutes. Blood pressure and pulse rate readings were made while the subjects were at rest, and every two or three minutes during exertion. Lactic acid was determined from blood samples taken at about the end of each run. The determinations of blood flow, oxygen consumption, and carbon dioxide output were made usually twice during each run, two or three readings being made on each occasion. The method used is discussed elsewhere by Bock,

TABLE 1.—EFFECT OF DIFFERENT LEVELS OF EXERTION: STATIONARY BICYCLE RIDING[1]

SUBJECT	TENSION ON BRAKE	PULSE (A)	BLOOD PRESSURE (B) Systolic	BLOOD PRESSURE (C) Diastolic	PULSE PRESSURE (B−C)	PULSE PRODUCT A × (B−C)	BLOOD FLOW	OXYGEN CONSUMPTION	CARBON DIOXIDE OUTPUT	RESPIRATORY QUOTIENT	LACTIC ACID IN BLOOD	REMARKS
	lbs.	*beats/min.*	*mm. Hg*	*mm. Hg*			*l./min.*	*c.c./min.*	*c.c./min.*		*mg./100 c.c.*	
D. B. D.	0.00	70	109	71	38	2,660	5.5[2]	250[2]	310[2]	0.80[2]	8.0[2]	Resting.
	4.65	105	123	76	47	4,940	21.9	1,347	1,202	0.88	11.7	
	6.35	135	138	70	68	9,185	20.4	1,816	1,778	0.97	21.3	
	9.25	145	153	80	73	10,585	18.7	2,090	2,217	1.05	.....	
	9.65	158	170	76	94	14,900	30.2	2,390	2,512	1.05	62.2	Blood pressures by A. V. B.
	10.10	136	151	77	74	10,064	.....	2,563	2,690	1.05	76.5	
Ed.	0.0	83	127	69	58	4,800	5.5[2]	250[2]	310[2]	0.80[2]	8.0[2]	Resting.
	0.0	102	138	77	61	6,227	16.7	806	614	0.76	.....	Working, but brake not attached.
	2.9	123	164	81	83	10,200	22.5	1,297	1,075	0.83	.....	
	6.7	156	182	75	107	16,700	23.5	2,037	1,881	0.92	31.0	
	8.5	170	195	72	123	20,900	25.7	2,528	2,422	0.96	81.3	
J. T.	0.00	88	100	74	26	2,288	5.5[2]	250[2]	310[2]	0.80[2]	8.0[2]	Resting.
	3.00	118	119	77	42	4,950	10.35	1,005	914	0.91	17.7	
	5.45	138	123	71	52	7,160	13.7	1,608	1,543	0.96	23.0	
	9.25	162	149	90	59	9,550	19.1	2,617	2,542	0.96	63.6	

[1] Figures are averages of a number of determinations in each run.
[2] Estimated.

Dill, and Talbott (8), and these actual figures will be used by them in another connection (9). The author is indebted to them for their co-operation in making this experiment possible.

Summary figures for these experiments are given in Table 1 and show that there is a definite tendency for the pulse product to rise with the greater oxygen consumption and blood flow

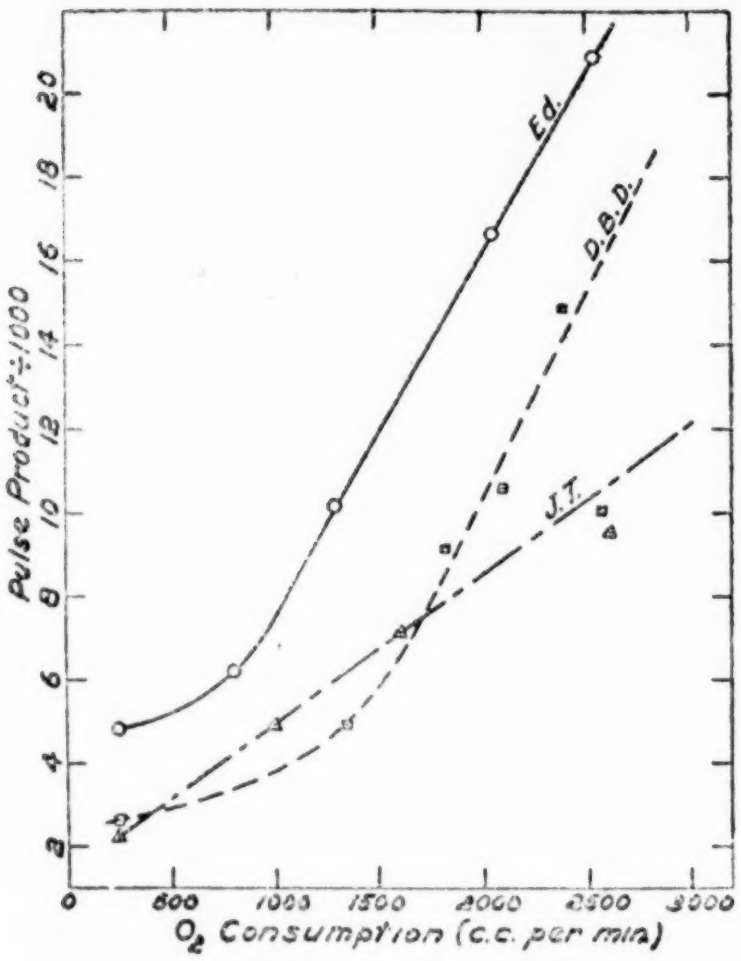

FIG. 1.—Pulse products and oxygen consumption of three subjects at different levels of exertion. Stationary bicycle riding.

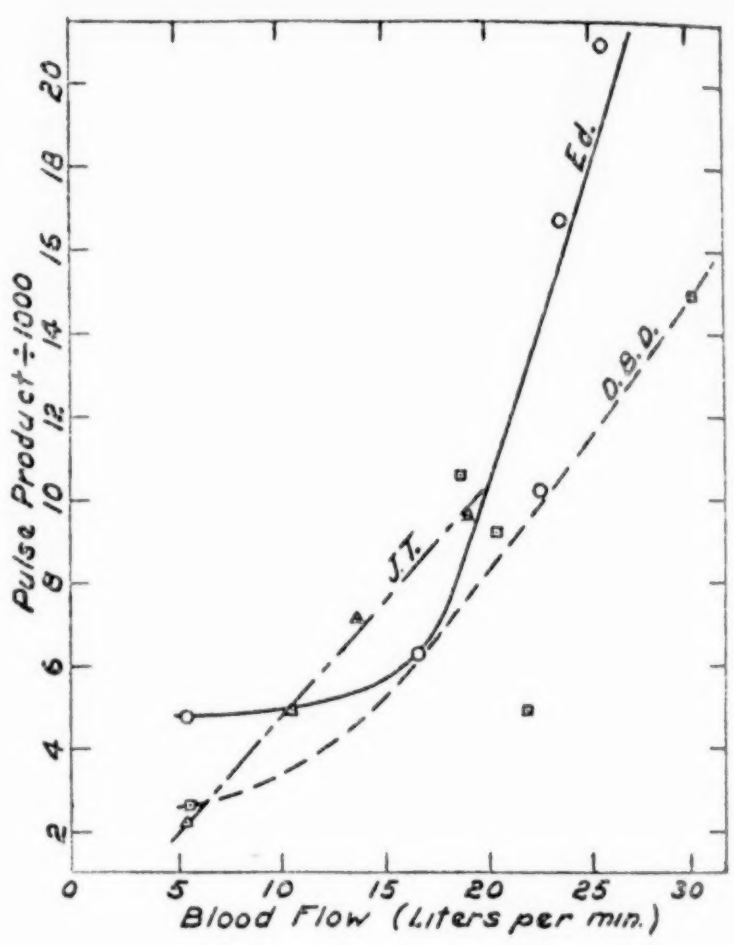

FIG. 2.—Pulse products and blood flow of three subjects at different levels of exertion. Stationary bicycle riding.

made necessary by increased exertion. Taking figures for each subject separately, this rise forms a fairly regular curve, particularly for the correlation between pulse product and oxygen consumption (Fig. 1). Pulse product when plotted against carbon dioxide output gives curves of almost the same shape. The curves correlating it with blood flow are not so regular, but the general rising tendency is the same (Fig. 2). When pulse pressure instead of pulse product is used, very similar curves are obtained.

Possible Factors Other than Exercise

Before accepting these increases in pulse product as being due solely to greater muscular activity, it is necessary to discuss briefly other factors which might affect them. Normal variations in systolic and diastolic pressures and in pulse rate have been found to depend on a number of factors besides exercise, chief among which are age, weight, body type (10, pp. 133–136), time of day (10, p. 80), and emotional state (10, p. 107). With respect to the first three, since the curves have been drawn in each case to fit the points obtained on individuals, and since each point on any one curve represents a single individual under different circumstances, variations between

individuals can be ruled out as far as these particular conclusions are concerned. Constitutional differences perhaps explain why the curves start at different levels and do not have the same slopes. With respect to diurnal variations, sleep and the taking of food seem to be the chief causes of fluctuation. In these experiments the first, of course, does not have to be considered, and the second may be taken as negligible, for two reasons:

1. The runs were made either between the hours of 10 and 11:30 A.M. or between 2:30 and 4:30 P.M. Although eating causes a rise in pulse product, its effects wear off by two and a half hours after the meal (11). All the experiments, with one exception, were at least this much later than breakfast or lunch.

2. The greatest fluctuation in their averages during the waking hours, as reported by Weysse and Lutz (11), amounted to a difference of 1,272 units in terms of pulse product. Since these experiments cover fluctuations between 2,000 and 20,000, the effects of eating, even if present, would be relatively unimportant.

With respect to emotional changes, which are known to have a marked effect on systolic pressure and pulse rate, one can say, in the case of these experiments:

1. The subjects were never in states of fright or anger. They were all experienced laboratory workers, had designed the experiment themselves, and were familiar with all the apparatus and procedures. Their attention was fully occupied with the conduct of the experiment.

2. The figures in the summary table, from which the curves have been made, represent averages of a number of blood pressure determinations. An emotion, to have any marked effect, must have lasted for the entire period of the experiment. This would eliminate the effect of transitory states of anxiety over the conduct of the experiment, to which an interested subject might be liable, and also transitory changes in pressure resulting from the forced breathing or the holding of the breath incident to the determinations of blood flow (3, p. 144).

One may conclude, then, that the variations in pulse product and pulse pressure found in these experiments are due chiefly to the varying levels of exertion, although individual differences cause the three curves to be of different relative heights and slopes. One may further conclude that the pulse product and pulse pressure of any one person doing muscular work tend to increase in direct relation to increased energy expenditure.

Relative Efficiency of Subjects

The amount of work turned out by these three subjects may be measured by the pounds' tension on the brake band, against which they kept the bicycle going at a uniform speed. We have discussed the measurement of the energy which they put into this production, and have concluded that it is measured by both oxygen consumption and pulse product. We are therefore in a position to estimate their relative efficiency as stationary bicycle riders.

Since the correlations are not exact in all cases, we can obtain a more reliable estimate by averaging the figures. Leaving out the resting readings, and the one run where the brake band was

not attached, we get the figures shown in Table 2. These figures indicate that the relative efficiency, measured in terms of both oxygen consumption and pulse product, is in the order: (1) D. B. D., (2) J. T., and (3) Ed.

To make comparisons easier, the efficiency figures can be expressed as percentages of the group average. It must be remembered, however, that the fluctuations of such a ratio above and below 100 will vary in extent with the average deviation of the series from which the ratio is computed. Thus the variations in this sort of efficiency ratio when measured in terms of oxygen consumption are less than when measured in terms of pulse product. Comparisons between individuals can be made only in the same series.

The actual efficiency of these three workers has been calculated by Dill and his coworkers (9) by reducing both output and input to gram-calories and is also shown in Table 2. Their relative rank is: (1) D. B. D., (2) J. T., and (3) Ed., with the first two very nearly equal.

TABLE 2.—RELATIVE EFFICIENCY OF THREE BICYCLE RIDERS[1]

SUBJECT	TENSION ON BRAKE	OXYGEN CONSUMPTION	PULSE PRODUCT	EFFICIENCY IN TERMS OF OXYGEN CONSUMPTION		EFFICIENCY IN TERMS OF PULSE PRODUCT		EFFICIENCY IN TERMS OF OUTPUT ÷ INPUT[2]	
	lbs.	*c.c./min.*		*lbs./c.c.*	%[3]	*lbs./unit*	%[3]	%	%[3]
D. B. D.	8.00	2,041	9,935	0.00387	114.5	0.00083	125.8	20.0	107.0
Ed.	6.03	1,954	15,933	.00296	87.6	.00036	54.5	16.3	87.2
J. T.	5.90	1,743	7,220	.00330	97.6	.00078	118.2	19.7	105.3
Group	6.64	1,913	11,029	.00338	100.0	.00066	100.0	18.7	100.0

[1] Averages for each subject, taken from Tables 1 and 3.
[2] Both terms expressed in gram-calories (from (9)).
[3] Of group average.

The foregoing ratings were calculated from average figures which included various speeds. Is there any change in the efficiency of an individual rider as he increases his energy expenditure? In other words, if he wanted to cover the greatest distance with the least expenditure of energy, at what speed should he pedal?

Efficiency ratios for different levels of exertion are given in Table 3 (data from Table 1). At first sight the trend of these figures seems to show that the harder the work is, the greater is the efficiency. In fact, if oxygen consumption alone were used as a criterion of efficiency, it would follow logically that the man who held his breath and pedaled furiously until he fell off would receive the highest rank. But the increased output per unit of oxygen consumption in the higher levels of exertion really occurs because the rider is building up an oxygen debt, not because he is more efficient. This is clearly shown in Table 3 by the increasing amounts of lactic acid. The glycogen-lactic acid cycle has been thrown out of equilibrium, and the

greater the extent of this unbalance, the shorter the time that the rider can continue. Benedict and Cathcart (quoted in 2, p. 16) found that the efficiency of bicycle riders reached its optimum at very moderate speeds, and fell off rapidly at higher speeds. If, then, one thinks of an efficient worker as one who maintains a high output for periods longer than a few minutes, one must consider not only the amount of oxygen used per minute, but the maintenance of equilibrium for longer periods. The trained Marathon runner can stay in equilibrium at high levels of exertion; the untrained man cannot (3, p. 144). To define efficiency as high output per unit of energy expenditure is not enough. This high output must be obtained under conditions of equilibrium.

A lack of equilibrium will be shown not only by an abnormal height, but by the extent of fluctuations in the curve of pulse product. If one takes blood pressure and pulse rate readings every two or three minutes throughout a twenty-minute run, one obtains a series of figures from which can be calculated an average or standard deviation. This has been done for the runs in the foregoing experiments (see Table 4). The standard deviation was calculated according to the formula

$$\sigma = \sqrt{\frac{\Sigma\ x^2}{N}}$$

where $\Sigma\ x^2$ is the sum of the squares of

TABLE 3.—EFFICIENCY AT DIFFERENT LEVELS OF EXERTION

SUBJECT	TENSION ON BRAKE	OXYGEN CONSUMPTION	PULSE PRODUCT	EFFICIENCY		LACTIC ACID IN BLOOD
				Oxygen Consumption	Pulse Product	
	lbs.	*c.c./min.*		*lbs./c.c.*	*lbs./unit*	*mg./100 c.c.*
D. B. D.	4.65	1,347	4,940	0.00345	0.00094	11.7
	6.35	1,816	9,185	.00349	.00069	21.3
	9.25	2,090	10,585	.00442	.00087	....
	9.65	2,390	14,900	.00404	.00065	62.2
	10.10	2,563	10,064	.00394	.00100	76.5
Average..	8.00	2,041	9,935	.00387	.00083	....
Ed.	2.90	1,297	10,200	.00224	.00028	....
	6.70	2,037	16,700	.00329	.00040	31.0
	8.50	2,528	20,900	.00336	.00041	81.3
Average..	6.03	1,954	15,933	.00296	.00036	....
J. T.	3.00	1,005	4,950	.00299	.00061	17.7
	5.45	1,608	7,160	.00339	.00076	23.0
	9.25	2,617	9,550	.00353	.00097	63.6
Average..	5.90	1,743	7,220	.00330	.00078	....

the several deviations from the arithmetic average, and N their number.

The fluctuations in pulse product between one reading and another tend to increase at first, but after the subject reaches a level of from 6,000 to 8,000 they drop off again in the case of the most efficient workers. In the range up to around 7,500 units there is

TABLE 4.—STANDARD DEVIATION OF PULSE PRODUCT READINGS AT DIFFERENT LEVELS OF EXERTION

SUBJECT	OXYGEN CONSUMPTION	PULSE PRODUCT		
		No. of Readings	Average	Standard Deviation
	c.c./min.			±
D. B. D.	250[1]	5	2,660	702
	1,347	8	4,940	1,012
	1,816	6	9,185	1,404
	2,090	4	10,585	846
	2,390	6	14,900	568
	2,563	3	10,064	482
Ed.	250[1]	5	4,800	790
	806	9	6,227	1,247
	1,297	10	10,200	792
	2,037	6	16,700	1,564
	2,528	8	20,900	849
J. T.	250[1]	2	2,288	155
	1,005	9	4,950	1,225
	1,608	5	7,160	671
	2,617	2	9,550	559

[1] Estimated figure for subject at rest.

sufficient lactic acid being formed so that the subject can hardly be called in equilibrium if one were considering a day's job as the basis. Increasing fluctuations in pulse product in these ranges, therefore, indicate a lack of equilibrium that is significant in factory work, where the pulse product rarely goes above 6,000. (We are here considering fluctuations as arising only from muscular exercise. The effect of emotions in causing fluctuations in the lower ranges will be considered later.)

In the higher levels the decreasing fluctuations of the pulse product of the best workers probably indicate that their circulatory systems are adequate to the increased load. The inefficient worker, on the other hand, when in those levels where he finds himself in distress, shows even more marked fluctuations.

The difficulty of making blood pressure and pulse rate readings increases as the exercise becomes violent. If there had been a continual rise in fluctuations between readings in all cases, one might have assumed that these fluctuations arose from increasing inaccuracy on the part of the observer. The decrease in fluctuations in the higher ranges, however, seems to indicate that they are not due to this.

Treadmill Experiments (Prolonged Muscular Exertion)

A series of blood pressure and pulse rate readings were made on subjects walking on a treadmill, which seem to bear out the conclusions derived from the bicycle experiments, although oxygen consumption and lactic acid figures were not obtained.

In Figure 3 are shown the pulse products of two normal subjects who walked at a constant speed of 4.6 miles per hour for approximately one hour, wearing a regulation army gas mask. D. B. D. was not in special training, but was accustomed to walking on the treadmill and to wearing the mask. He had been an athlete in college. O. S. L. was not in training and had walked on the treadmill only once or

twice previously. He was not used to the gas mask. The two subjects show very different types of blood pressure readings in the resting state, and part of the marked difference in the exercise curves is undoubtedly due to this difference in constitution. Even allowing for this, the curves show that given exactly equal loads, the efficient

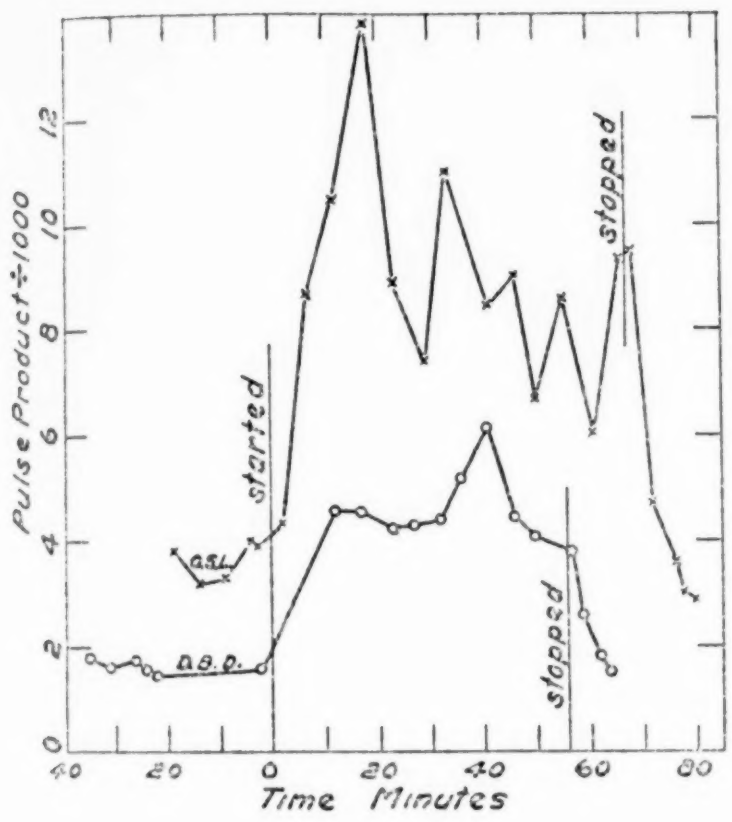

FIG. 3.—Pulse products of two subjects under equal loads. Walking on treadmill at rate of 4.6 miles per hour, and wearing gas mask.

person tends to have a lower and smoother pulse product curve than the inefficient.

D. B. D. apparently had no great difficulty in doing this work. O. S. L. reported afterward that several times during the experiment he almost had to stop; that once, when about halfway through, he nearly fainted, and from that time on he was worried for fear he might faint suddenly and both hurt himself as he fell off the treadmill and smash the apparatus involved in testing the gas mask. In his case the lack of equilibrium is not only in the glycogen-lactic acid cycle but in emotional control, and the irregularities in blood pressure are, no doubt, partly due to this.

Tables 5 and 6 show the readings made on subject O. S. L. during two four-hour walks on the treadmill. On the first occasion the pace of 3.5 miles per hour was reduced for seventy minutes to 2.6 miles per hour, during which interval the subject wore a gas mask. On the second occasion the subject walked at the rate of 3.5 miles per hour the entire time. If we take the averages at the 3.5-mile pace on the first walk, there is little difference between the pulse, pulse pressure, and pulse product averages on the two occasions. The first occasion shows higher systolic and diastolic pressures. The subject was in better training for the second walk than for the first; he had also had a full night's sleep before beginning the experiment, whereas he had been at a dance the night before the first walk. In general the second walk caused him less distress than the first, but on both occasions he found that the pace was distinctly fatiguing and that he was working under a greater muscular load, unrelieved by any break, than is ever found under factory conditions.

The question arises as to whether any changes in efficiency could be determined as the time progressed. The output of work is constant; the only variable is the expenditure of energy. Examination of the two tables shows an initial rise in pulse product followed soon by an adaptation to the load. After this there seems to be a gradual rise on the first occasion, but a rather rhythmic fluctu-

TABLE 5.—O. S. L. FIRST LONG DISTANCE WALK

TIME	REMARKS	PULSE	BLOOD PRESSURE		PULSE PRESSURE	PULSE PRODUCT
			Systolic	Diastolic		
		beats/min.	*mm. Hg*	*mm. Hg*		
8:30	Lying down	78	126	74	52	4,056
8:32	Standing	92	130	86	44	4,048
8:34	"	102	140	84	56	5,712
8:36	Started walking at 3.5 miles per hour	120	150	76	74	8,880
8:40		104	150	80	70	7,280
8:45		108	160	74	86	9,288
8:50		112	140	78	62	6,944
9:00		100	140	80	60	6,000
9:20	Pulse more steady	98	134	76	58	5,684
9:40		108	132	74	58	6,264
10:00	Felt fatigued	100	140	70	70	7,000
10:20		104	140	74	66	6,864
10:40	Felt O.K. Speed reduced to 2.6 miles per hour	104	140	70	70	7,280
10:45		94	120	70	50	4,700
11:00	Put on gas mask	92	120	80	40	3,680
11:03		94	132	78	54	5,076
11:11		100	136	82	54	5,400
11:16		94	130	80	50	4,700
11:20		90	130	80	50	4,500
11:26		94	136	80	56	5,264
11:31		88	138	70	68	5,984
11:36		104	140	70	70	7,280
11:40		94	140	80	60	5,640
11:42		94	124	70	54	5,076
11:50	Removed gas mask. Speed raised to 3.5 miles per hour					
	Average at 2.6 miles per hour.....	94.4	131.5	76.4	55.1	5,209
11:55		112	142	74	68	7,616
12:00		104	144	78	66	6,864
12:20		104	142	68	74	7,696
	Averages at 3.5 miles per hour.....	106.0	142.6	74.8	67.8	7,205
	Standard deviation.....					±985
12:40	Stopped walking	112	124	82	42	4,704
12:45	Lying down	84	118	70	48	4,032
12:50	Standing	110	106	84	22	2,420
12:52	"	110	104	86	18	1,980

TABLE 6.—O. S. L. SECOND LONG DISTANCE WALK

TIME	REMARKS	PULSE	BLOOD PRESSURE		PULSE PRESSURE	PULSE PRODUCT
			Systolic	Diastolic		
		beats/min.	*mm. Hg*	*mm. Hg*		
9:09	Lying down	84	112	56	56	4,704
9:11	Standing	92	102	54	48	4,416
9:13	"	110	110	58	52	5,720
9:15	Started walking at 3.5 miles per hour	100	124	60	64	6,400
9:17		96	130	56	74	7,104
9:20		108	108	60	48	5,184
9:23		108	122	50	72	7,776
9:25		108	122	58	64	6,912
9:30		100	130	50	80	8,000
9:40		108	132	54	78	8,424
9:50		96	118	54	64	6,144
10:00		96	120	52	68	6,528
10:20		104	122	50	72	7,488
10:33	Stopped ½ minute to fix shoe lace					
10:40		104	118	50	68	7,072
11:00		98	104	52	52	5,096
11:20		100	120	60	60	6,000
11:40	Pulse wavy; sometimes strong, sometimes weak	104	114	48	66	6,864
12:00		108	112	46	66	7,128
12:20		104	110	46	64	6,656
12:40	Pulse hard to count; seems to disappear	108	104	58	46	4,968
1:00		102	130	50	80	8,160
1:15	Stopped	110	130	50	80	8,800
	Average at 3.5 miles per hour.....	103.3	119.5	52.8	66.7	6,879
	Standard deviation.....					±1,070
1:16	Lying down	96	114	56	58	5,568
1:21	" "	84	106	56	50	4,200
1:23	Standing (pulse weak)	108	88	58	30	3,240
1:25	" " "	112	96	60	36	4,032

ation, with a general downward trend, on the second. One might assume that the rising curve during the first walk indicated more fatigue and progressing inefficiency than occurred during the second. This would be confirmed by the facts that the first walk was more tiring and that its effects were felt longer by the subject. Whether one can draw any conclusion from this with respect to factory work is doubtful. In the first place, the

work was much harder, even on the second walk, and yet no marked changes are evident. In the second place, however, ordinary daily fatigue in a factory job might accentuate any emotional instability, which *would* cause marked changes in a curve at lower levels. Probably one cannot draw any conclusions from this experiment with respect to factory situations, other than that it confirms the previous conclusion that height of pulse product varies directly with the amount of energy expended.

Typewriting Experiment (Sustained Attention)

We have discussed so far experiments involving heavy muscular work and a constant load. It is obvious that although in a sense artificial conditions, these are, at the same time, the simplest set of circumstances from which one might draw conclusions, because:

a. Heavy muscular work keeps the effect of changes in emotion or in attention from having an important effect on our readings.

b. From the fact that the load is constant, it follows that variations in energy expenditure (1) as between different people, indicate their relative efficiency, and (2) as between periods of work, may indicate changing efficiency in the same person.

It is obvious, however, that in practical work such artificially simple conditions will not often be met. An experiment was needed, therefore, to test the value of these readings under more nearly normal conditions, such as might be found in a factory or an office. For this experiment a subject was set the task of copying on a typewriter all day. He was already familiar with the touch system, so the effect of training is probably not important. He worked as fast as possible, not stopping to correct mistakes. It was necessary to cease work for approximately two minutes each time that blood pressure readings were made, which was every twenty minutes except for the first half hour in morning and afternoon, when readings were made every ten minutes. The hours of work were from 9:11 to 12:40 and from 1:31 to 5. The subject ate no breakfast, but ate his usual lunch. A record was kept of the times when work was suspended, and the production record was corrected to allow for these interruptions. The production record was kept in terms of letters struck, so that each unit of production represents a very small unit of time, and such correction is thus as accurate as possible. A record of mistakes was also kept, which showed a slight increase toward the end of the day. Fluctuations in this quality index, however, were not so great as had been expected; the chief variations occurred in the quantity record, and in the ensuing calculations this record is, therefore, the only one to be used.

This experiment was therefore one which demanded only a slight amount of muscular exertion but a high degree of coordination, and continued attention to uninteresting detail. (The material chosen to be copied had a context so difficult that the worker made no attempt to follow it, and concentrated all his effort on the work of typing.)

The height and the general shape of

the blood pressure and pulse rate curves are shown in Figure 4. The actual figures are given in Table 7. There is also included a record of production per minute in the five-minute period preceding each blood pressure reading.

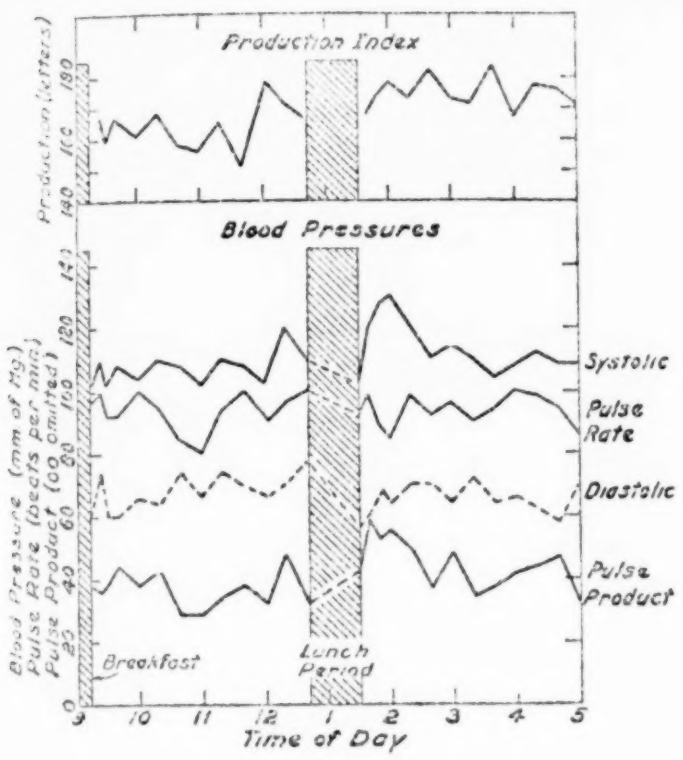

FIG. 4.—Daily record of one subject working on typewriter.

The day's average for the pulse product turned out to be 4,080 with a standard deviation of ±672. When individual readings for pulse product are plotted against production in the five minutes preceding each reading, there is no correlation. This negative result, however, should not be taken as disproving the conclusion already reached, that an increased pulse product goes with an increased energy expenditure, because we are not dealing here with a constant load. A low production might still indicate efficiency if but little energy was expended to maintain it. To elaborate this further, there are four situations that might be imagined:

Production compared with average	*Energy Expenditure*	*Characterization of Worker*
1. High	Low	Skilled.
2. High	High	Strenuous, but not necessarily efficient.
3. Low	Low	Sluggish, but not necessarily inefficient.
4. Low	High	Unskilled.

If one supposes that there are variations in a worker's efficiency throughout the day, one could not possibly get a straight line correlation between high production and a high energy expenditure, because that would assume that his work always fell in either category 1 or 3. As a matter of fact, in his best periods it will fall in category 2, and when he is fatigued it may fall in category 4.

One can get an idea of the extent of such variations in skill by dividing the day into periods and working out periodic efficiency ratios. This has been done in Table 8. The efficiency ratios are obtained as before, by simplifying the fraction $\frac{\text{output}}{\text{input}}$ and stating the result as a percentage of the day's average. Thus, a ratio of more than 100 per cent. means simply better than average by a certain amount, and a ratio of less means less than average.

When one considers a day's work as a whole, and not isolated sprints such as those of the first experiments, it is necessary to take account of normal diurnal variations in blood pressure and pulse rate. That these may be considerable was shown by Weysse and Lutz (11) in a study of ten normal medical students whose blood pressures

were taken hourly when they were working under standard conditions, mum before the next meal. The curve as a whole showed a very slight rising

TABLE 7.—TYPEWRITING EXPERIMENT

TIME	REMARKS	PULSE	BLOOD PRESSURE		PULSE PRESSURE	PULSE PRODUCT	PRODUCTION RATE DURING 5 MINUTES PRECEDING
			Systolic	Diastolic			
		beats/min.	*mm. Hg*	*mm. Hg*			*letters/min.*
9:11	Just before start	96	100	60	40	3,840	...
9:21	Visitor between 9:15 and 9:20	100	110	74	36	3,600	167
9:30		92	102	60	42	3,864	159
9:40		92	108	60	48	4,416	167
10:00		100	104	66	38	3,800	161
10:20		94	110	64	46	4,324	168
10:40		84	108	74	34	2,856	158
11:00		80	102	66	36	2,880	156
11:20		94	110	74	36	3,384	165
11:40		100	108	70	38	3,800	151
12:03		90	102	66	36	3,240	178
12:20		96	120	70	50	4,800	172
12:40		100	110	78	32	3,200	167
	Morning average	93.7	107.2	67.8	39.4	3,693	...
1:30	Just before beginning work	92	102	56	46	4,232	...
1:40		98	120	60	60	5,880	168
1:50		88	128	68	60	5,280	174
2:00		84	130	64	66	5,544	178
2:20		98	120	70	50	4,900	173
2:40		92	110	70	40	3,680	182
3:00		96	114	64	50	4,800	173
3:20		90	110	72	38	3,420	171
3:40		94	104	64	40	3,760	183
4:00		100	108	66	42	4,200	167
4:20		88	112	62	50	4,400	177
4:40		94	108	58	50	4,700	176
5:00		86	108	70	38	3,268	171
	Afternoon average	92.3	113.4	64.9	48.5	4,466	...
	Day's average	93.0	110.3	66.4	44.0	4,080	...
	Standard deviation					±672	

which included no strenuous muscular exertion. The average curve showed a rise after each meal, followed by a gradual decline which reached a minitendency all day long, attributed by the authors to the cumulative effects of the day's meals.

In any curve taken during a day's

work, one must expect to have fluctuations caused by altered skill or efficiency superimposed on these normal fluctuations. It would perhaps be possible to correct for them in a curve made up of average figures, but to correct the curve of an individual would result in only an approximation, since Weysse and Lutz report that individuals fluctuate considerably around their average. Although one cannot be sure, therefore, that one has eliminated all such effects, a correction has been made in the figures for pulse product in Table 8. This was done by plotting the figures from Weysse and Lutz' article on a time chart and interpolating a percentage correction (based on the day's average as 100 per cent.) for the various times of day when readings were actually made. These correction percentages are shown in Table 9. No correction was made for the morning readings since the subject ate no breakfast. It seems to be assumed that most of the diurnal fluctuations arise from eating. Erlanger and Hooker (7) made one series of readings during a morning on one subject who had eaten nothing. The curve showed a declining trend, but one could not base a correction percentage on readings made from a single subject. It is possible in the present case that because of the lack of breakfast the curve rose more than usual after lunch, although the amount of food taken did not seem to affect Weysse and Lutz' figures.

The final column in Table 8 characterizes the work of each period, and shows that the morning was not on the whole so productive as the afternoon, nor was so much energy put into the work. An examination of the subject's introspective report shows that

TABLE 8.—DIURNAL VARIATIONS IN EFFICIENCY: TYPEWRITING EXPERIMENT

PERIOD	CORRECTED PULSE PRODUCT	PRODUCTION	EFFICIENCY IN TERMS OF PULSE PRODUCT		CHARACTERIZATION OF WORK
		letters/min.	*letters/unit*	%[1]	
9:11- 9:40	3,768	1,637	0.4344	104.4	Sluggish.
9:41-10:10	4,108	1,595	.3883	93.3	Unskilled.
10:11-11:10	3,353	1,614	.4814	115.7	Sluggish.
11:11-12:10	3,475	1,661	.4780	114.9	Sluggish.
12:11-12:40	4,000	1,691	.4228	101.6	Skilled.
12:41- 1:30	Lunch period				
1:31- 2:00	4,276	1,660	.3882	93.3	Unskilled.
2:01- 2:30	4,835	1,744	.3607	86.7	Strenuous.
2:31- 3:30	3,778	1,767	.4677	112.4	Skilled.
3:31- 4:30	4,337	1,704	.3929	94.4	Strenuous.
4:31- 5:00	4,927	1,703	.3456	83.1	Strenuous.
Day's average.....	4,086	1,678	.4160	100.0	.....

[1] Of day's average.

he felt hungry and "low" during the morning. He also mentions the spurt which raised the production in the last half hour of the morning.

These figures show that although the phlegmatic or sluggish worker may not turn out a high production, he may, in the strict sense of the term, be relatively efficient, if he is expending but little energy. Conversely, the high producer may be working unduly hard and may be relatively inefficient.

One can draw the following conclusions from this experiment:

A curve extending throughout a day must be corrected for normal diurnal variations, or at least their possible effect must be remembered before conclusions as to efficiency are drawn.

A low pulse product (energy expenditure) when found with a low production figure will, it is true, give a high efficiency ratio, but this ratio may not of itself indicate a good worker or a good period of work. The absolute height of the output and input figures must also be considered.

TABLE 9.—CORRECTION PERCENTAGES FOR PULSE PRODUCT TO ALLOW FOR DIURNAL VARIATIONS DUE TO FOOD

ACTUAL TIME	LENGTH OF TIME AFTER MEAL	PULSE PRODUCT[1]	CORRECTION PERCENTAGE[2]
7:30 a.m.	(½ hour before)	2,165	82.4
8:00	(Just before)	2,094	79.7
8:30	Immediately	3,081	117.3
9:00	½ hour	3,313	126.2
10:00	1½ hours	2,446	93.1
11:00	2½ "	2,126	81.0
12:00 m.	3½ "	2,065	78.6
12:30 p.m.	Immediately	2,808	106.9
1:00	½ hour	3,212	122.3
2:00	1½ hours	2,871	109.3
3:00	2½ "	2,719	103.5
4:00	3½ "	2,420	92.2
5:00	4½ "	2,352	89.6
6:00	5½ "	2,402	91.5
6:45	Immediately	3,337	127.1
7:00	¼ hour	3,120	118.8
7:30	¾ "	2,801	106.7
8:00	1¼ hours	2,502	95.3
8:30	1¾ "	2,394	91.2
9:00	2¼ "	2,298	87.5
Day's average		2,626	100.0
Standard deviation		±408.6	

[1] From figures by Weysse and Lutz (11).

[2] Based on day's average as 100.

Pulse Product Correlated with Attention and Emotion

It has been mentioned that one would not expect to find a correlation

between high production and high energy expenditure in all cases, since this would assume a constant degree of skill. The fact that an increasing pulse product indicated greater energy expenditure could thus never be proved by correlating pulse product with production alone. A second series, itself indicating degree of energy expenditure, must correlate with the pulse product. In the case of muscular work, oxygen consumption furnished this second series. In the case of both mental work and emotion, we have been assuming that some such second series existed, even though only of a qualitative nature. We have already cited references dealing with the rise in systolic pressure and in pulse rate in emotion; others exist (12) (13) dealing with a corresponding rise with increased attention as distinct from emotion. It is perhaps not too much to assume that both emotion and attention involve an increased energy expenditure even though it cannot be measured by gross changes in oxygen consumption, or in blood flow. The common sense knowledge that periods of mental, as well as of muscular, work can cause a feeling of fatigue is sufficient justification for such a practical assumption.

One other experiment, however, was desired, to correlate an introspective report showing fluctuations in attention or emotion with corresponding changes in pulse product. For this experiment a subject reclined on a couch in a half-sitting position the whole day, leaving it only for meals. Blood pressure and pulse rate readings were taken at least every twenty minutes throughout the day. These will be found in Table 10, and in graphic form in Figure 5. At the close of the experiment the subject wrote an introspective report of his feelings and mental activities as nearly as he could remember them. Data from this report also are summarized in Table 10, and the periods during which undoubted changes in attention or emotion occurred are numbered alike in both table and chart.

The day's average for the pulse product was 3,819, with a standard deviation of ±535. The general shape

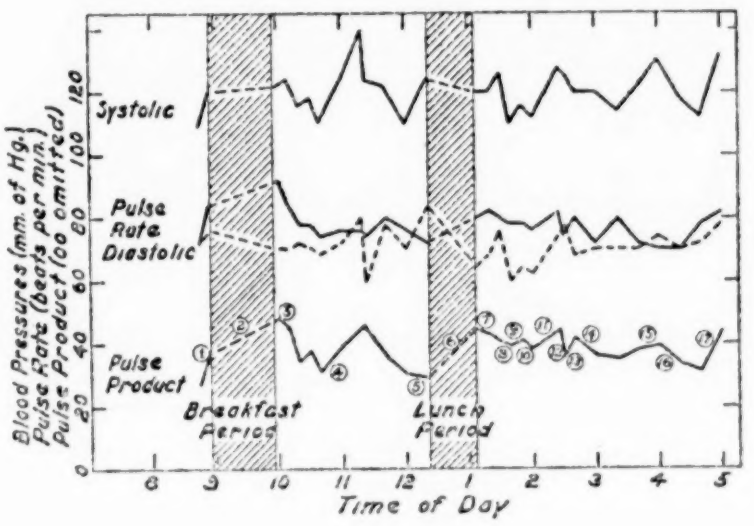

FIG. 5.—Changes in pulse product with changes in attention or emotion.

of the curves, particularly those for pulse product and pulse pressure, shows diurnal variation of the type reported by Weysse and Lutz. Upon these basic curves are superimposed a number of added fluctuations. In only two cases could these fluctuations have any direct relation to muscular exercise, namely, the readings just after the breakfast and lunch periods, when the subject had to walk a few hundred yards to return to his couch. In all other cases variations were due to mental and emotional factors. Since the chief interest in this experiment was to observe the change from one

TABLE 10.—EFFECT OF CHANGES IN ATTENTION AND EMOTION ON BLOOD PRESSURE AND PULSE RATE

TIME	PULSE	BLOOD PRESSURE		PULSE PRESSURE	PULSE PRODUCT	CHANGE EROM PRECEDING PERIOD		REFERENCE NO.	CAUSE OF CHANGE IN ATTENTION OR EMOTION
		Systolic	Diastolic			Attention	Emotion		
	beats/min.	*mm. Hg*	*mm. Hg*						
8:45	72	110	72	38	2,736				
8:54	84	120	76	44	3,696	Increased	Increased	1	Maid announced breakfast.
	Breakfast period								
9:49	Lay down on couch again								
10:00	92	122	70	52	4,784	Increased	Increased	2	Business affairs. Food.
10:10	84	124	70	54	4,536	Decreased	Decreased	3	Relaxation.
10:20	78	116	72	44	3,432				
10:30	78	118	70	48	3,744				
10:40	74	110	68	42	3,108				
11:00	76	124	72	52	3,952	Increased		4	Began to read.
11:20	76	140	80	60	4,560				
11:22	74	124	64	60	4,440				
11:40	80	122	78	44	3,520				
12:00	76	110	70	40	3,040				
12:20	72	124	84	40	2,880	Decreased		5	Reading, but decreased attention.
12:21	Lunch period								
1:01	Lay down on couch again								
1:07	80	120	64	56	4,480	Increased		6	Lunch and conversation.
1:20	82	120	68	52	4,264	Decreased		7	Relaxation after lunch.
1:30	80	126	76	50	4,000				
1:40	78	110	60	50	3,900	Decreased		8	Felt sleepy.
1:50	78	116	64	52	4,056	Decreased		9	Felt very sleepy. Struggled to keep awake.
2:00	76	112	62	50	3,800	Decreased		10	Same.
2:25	82	128	74	54	4,428	Increased	Increased	11	Telephone rang. Conversation.

2:30	74	126	78	48	3,552	Decreased	Decreased	12	Relaxed after telephoning.
2:40	80	120	68	52	4,160	Increased		13	Conversation with visitor.
3:00	72	120	70	50	3,600	Decreased		14	Visitor left. Listless reading.
3:20	80	114	70	44	3,520				
3:40	72	122	70	52	3,744				
4:00	70	130	74	56	3,920		Increased	15	Exciting reverie.
4:20	70	118	70	48	3,360		Decreased	16	Reverie gone.
4:40	78	112	72	40	3,120				
5:00	82	132	78	54	4,428		Increased	17	Annoyance, coughing.
Average.....	77.6	120.3	71.2	49.2	3,819				
Standard deviation...					±535				

reading to another, no attempt was made to correct for diurnal variations.

In Table 11 is given a summary of all changes in attention and emotion, compared with simultaneous changes in blood pressure and pulse rate factors. Because the psychologic measurements were recorded only qualitatively, no attempt was made to give quantitative estimation to organic changes. Only those psychologic changes which could unmistakably be traced to the introspective report are shown in Table 10, but these account for two-thirds of the total number of changes in pulse product. It is evident from Table 11 that there is a more direct correlation between changes in attention or emotion and changes in pulse product than for any other blood pressure or pulse rate factor.

Some sort of further experiment is needed to get a quantitative measure of the changes in attention and emotion. There is, for example, a rise in the pulse product curve between 10:40 and 11 A.M., when the subject began to read. He continued reading until 12 noon, stating that he paid continuous attention to the book during this entire period. The pulse product curve, however, rises until 11:20 and then falls. Without some quantitative measure of attention one cannot say whether this fall is due to a decline in effort, to an increased efficiency in attention, or to the fact that the pulse product varies merely with *changes* from passivity to activity. A sense of strain or effort may be an accompaniment of attention under difficulties rather then an indication of efficient attention (14). Here, as in muscular work, the most highly skilled worker will show the greatest output for a

TABLE 11.—CORRELATION BETWEEN QUALITATIVE CHANGES IN BLOOD PRESSURE AND PULSE RATE FACTORS AND FLUCTUATIONS IN ATTENTION AND EMOTION[1]

BLOOD PRESSURE AND PULSE RATE FACTOR	ATTENTION		EMOTION	
	Increased	Decreased	Increased	Decreased
Pulse:				
Increased	6	1	4	0
Unchanged	0	1	0	1
Decreased	0	6	1	2
Systolic Pressure:				
Increased	4	3	5	1
Unchanged	0	2	0	0
Decreased	2	3	0	2
Diastolic Pressure:				
Increased	3	5	4	1
Unchanged	0	1	0	1
Decreased	3	2	1	1
Pulse Pressure:				
Increased	6	2	5	1
Unchanged	0	2	0	0
Decreased	0	4	0	2
Pulse Product:				
Increased	6	1	5	0
Unchanged	0	0	0	0
Decreased	0	7	0	3
Total	6	8	5	3

[1] Figures refer to number of changes noted.

given level of energy expenditure. It is never true, of course, that attention remains for a long period at exactly the same level, but to catch the constant variations would require much more frequent blood pressure determinations. Further research on this point would perhaps be better carried on with the aid of the psychogalvanometer than with the sphygmomanometer.

Certainly from the present experiment one can conclude that increased attention and emotion cause a rise in the pulse product, but without muscular work one cannot say that this rise is correlated with an increased oxygen consumption or blood flow. Between 10:40 and 11:20 the subject's pulse product went from 3,108 to 4,560, with the increased attention of taking up a book and reading. No more than insignificant changes occurred in his total ventilation or probably in his flow of blood per minute. Just as in muscular exercise one must remember that a rise in blood pressure does not necessarily imply any increase in peripheral resistance, but probably a net decrease (10, p. 20), accompanied by increased blood flow, so in mental and emotional changes a rise in blood pressure may mean not only a rise in blood flow, but also an increase in peripheral resistance. Norris (10, p. 32) estimates that a 12 per cent. diminution in the length of the circular muscle fibers of all the arterioles at once, would mean almost a doubling of the mean blood pressure, if the minute-volume were to be kept constant. This hypothetical situation shows how much effect the peripheral resistance may have on blood pressure. Investigators working with a plethysmograph have shown a decrease in volume of a limb in increased attention (15) and in emotions involving alarm or defense reactions (16). It is well known that an increase in sympathetico-adrenal activity causes vasoconstriction in the splanchnic area

and in other areas where local activity does not cause a lowered peripheral resistance (17, p. 420).

The fluctuations in the two chief variables that influence blood flow are summarized in Table 12.

TABLE 12.—EFFECT OF FLUCTUATIONS IN HEART ENERGY AND PERIPHERAL RESISTANCE ON BLOOD FLOW

FACTOR CAUSING FLUCTUATION	HEART ENERGY	PERIPHERAL RESISTANCE	BLOOD FLOW
Muscular work	Increased	Net decrease	Increased.
Mental work	Increased	Increased	Unchanged or increased.
Emotion unaccompanied by muscular work	Increased	Increased	Unchanged or increased.

Conclusions

One may summarize the conclusions to be drawn from the laboratory experiments as follows:

1. The measurement of human efficiency should involve records of both production and energy expenditure. The efficient worker is he who (*a*) has a high production per unit of energy expenditure and (*b*) maintains physiologic equilibrium at this level of exertion.

2. In muscular work the pulse pressure and pulse product are useful measures of energy expenditure, correlating with oxygen consumption. Supposing that one has allowed for constitutional differences in blood pressure readings, of two workers turning out equal production the more efficient has (*a*) the lower figure for pulse product and (*b*) the lower figure for standard deviation in a series of pulse product readings.

3. In mental work and in emotion the pulse product is raised. Variation in pulse product follows changes in attention or emotion more closely than does any other blood pressure or pulse rate factor. Here also the more efficient worker, of two turning out equal production, will have the lower and smoother curve for pulse product. A continued high curve would indicate not so much efficiency of attention as a high degree of strain, and high fluctuations would indicate either lack of ability to fix and sustain attention, or lack of emotional control, or perhaps both.

4. There are normal diurnal variations in blood pressure and pulse rate due, in the working day, chiefly to the taking of food. Correction may be made for these variations, particularly in average curves.

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(To be concluded)

BOOK REVIEW

PSYCHIATRY IN INDUSTRY. By *V. V. Anderson*, M.D., M.A., Director of Medical Research, R. H. Macy & Co., Inc. Cloth. Pp. xv, 364 with appendixes and index. New York and London: Harper & Brothers, 1929.

In this book, Dr. Anderson gives the reader a good picture of the work which he organized during his first four years with R. H. Macy and Company of New York City. During those years his work was largely on an advisory basis, centering about what he has called the Conference Room. After an absence of about a year, Dr. Anderson again became attached to the staff of the store but in a new capacity—in charge of employment and placement.

The first few years, then, represent a more or less experimental attempt, a groping for practical methods, utilizing psychiatry and psychology to solve, in part at least, a number of the pressing problems in employment and placement. Apparently Dr. Anderson has done this to the satisfaction of the management at Macy's.

Probably the most useful part of Dr. Anderson's new technic is that which deals with the selection of executives. In Chapter III, he gives the method he has employed for this purpose.

Dr. Anderson has also made quite an intensive study of work failures, and has found that approximately 20 per cent. of the employees of mercantile establishments are what may be called "problem individuals." Work failures are classified into four groups: (1) those for whom psychiatric treatment within their own department secures satisfactory results; (2) those for whom transfer is necessary; (3) those who, after an initial psychiatric examination, are recommended for lay off; and (4) those for whom treatment has been tried but has failed.

Dr. Anderson states that out of 500 problem cases which were considered worth studying, 67 per cent. are still in the store, 23 per cent. have been laid off, 8 per cent. have resigned, and 2 per cent. have been pensioned. Of the active cases, 40 per cent. have been adjusted and no longer furnish a problem to their departments, while 44.7 per cent. are still under treatment.

Other valuable chapters are those dealing with Scientific Job Placement and Guidance for Young Workers; Job and Personnel Surveys; and Psychiatry in Industrial Health Work. Two other practical chapters are Chapter VII, A Scientific Guide for Employment Interviewers; and Chapter IX, Automobile Accidents and their Prevention. Chapter X describes the various psychologic tests which were utilized by Dr. Anderson and his staff in connection with their work.

Dr. Anderson states in his book that the ideal working team in industry or in business is composed of a psychiatrist, a psychologist, and a psychiatric social worker. With this statement the reviewer does not agree, except for research purposes and in special instances where the industrial organiza-

tion is so large as to make it economically worth while. The reviewer believes that Dr. Anderson has since changed his mind and is now in agreement with him in the belief that what industry and business really need at the present time are executives doing employment or placement work who have had an opportunity to acquire an understanding and appreciation of psychiatry and psychology as applied to industry or business.

Every person concerned with the human factor either in business or in industry should read this book.—*Henry B. Elkind.*

OBITUARY

HENRY WILLIAM ARMIT, M.R.C.S., L.R.C.P.

We regret to announce the death in Sydney, New South Wales, on March 12, of Dr. H. W. Armit, at the age of 59. Since the commencement of THIS JOURNAL he had been an Associate Editor and its representative in Australia. Only so recently as January, 1929, we published an article by him describing the development of industrial hygiene in Australia, wherein he displayed the faith he held in the value of healthy workers as a moving force in the world's progress. His father was William Armit, one-time secretary to the Hudson Bay Company. He was educated at St. Bartholomew's Hospital, whence, in 1894, he became a member and licentiate of the Royal Colleges. After that for a time he was Assistant Medical Officer at the Eastern Hospital of the Metropolitan Asylums Board; next he was attached to the Lister Institute. But journalism always tempted him; he was particularly fitted for it on account of his knowledge of languages and his broad vision of life. He represented the *British Medical Journal* at many international congresses; at Berlin in 1901 and 1907; at Paris in 1905; at Lisbon in 1906; at Cologne in 1908; and at Budapest in 1909. His services as a German scholar were utilized for translating the well-known book on "Anaemia" by Ehrlich and Lazarus, and also the "Hygiene of the Lung" by Von Schrötter.

He was summoned to Australia in 1914 to take the post of editor of the newly established *Medical Journal of Australia*, of which he also became the business manager. The success of that Journal must always be the lasting monument to Armit's life. Unfortunately his desire to make the printing office of the Journal a practical example of modern industrial hygiene—in the financial success of which he had deep-rooted faith—did not meet with support from the owners of the Journal. Only last year he had reluctantly to surrender the business side of the work, when he felt that he was surrendering a great ideal. He hoped that he might yet have found opportunity elsewhere to devote his services more wholly to advancing the cause of industrial hygiene. But the fates ruled otherwise.